PB87-129813

Pilot Plant Demonstration of the Hyperbaric Oxyozosynthesis Process

Monroe County Office of the Drain Commissioner, MI

Prepared for

Environmental Protection Agency, Cincinnati, OH

Dec 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-129813
EPA/600/2-86/103
December 1986

PILOT PLANT DEMONSTRATION OF THE HYPERBARIC OXYOZOSYNTHESIS PROCESS

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U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/2-86/103		PB87 129813/AS

4. TITLE AND SUBTITLE
Pilot Plant Demonstration of the Hyperbaric Oxyozosynthesis Process

5. REPORT DATE
December 1986

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Greenhorne & O'Mara, Inc. and HydroQual, Inc.

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Monroe County Drain Commissioner County Agency
111 Conant Street
Monroe, Michigan 48161

10. PROGRAM ELEMENT NO.
CNVB1E

11. CONTRACT/GRANT NO.
Cooperative Agreement No. CR 810765

12. SPONSORING AGENCY NAME AND ADDRESS
Water Engineering Research Laboratory-Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Research 8/1/83 - 7/1/85

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Harry E. Bostian (513) 569-7619, FTS-684-7619

16. ABSTRACT

A 3-month field demonstration study was conducted on the hyperbaric oxyozosynthesis process for sludge conditioning and stabilization at the Monroe, Michigan Metropolitan Area Wastewater Treatment Facility. The process involves contacting sludges, under pressure, and at reduced pH of 3 to 4, with oxygen and ozone for periods of up to three hours.

The primary objective of this study was to evaluate the process with respect to its effect on sludge dewaterability, as measured by the Buchner funnel specific resistivity test. The process had been demonstrated previously for sludge stabilization measured by bacteria destruction. The present study confirmed that advantage, also the ability to reduce odors. The findings of the present study indicate that the oxyozosynthesis process did not improve sludge dewaterability, but actually decreased dewatering characteristics somewhat. Also, the oxyozosynthesis process did not achieve any significant reduction of sludge volatile solids or total chemical oxygen demand.

Comments received after completion of the project from Ozonics Corporation, who presently has license rights to the process, are included in the Appendix to the report.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	Unclassified	85
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a communication link between the researcher and the user community.

The project described in this report was concerned with an evaluation of a process for treating the sludge residue resulting from municipal wastewater treatment. The process involves contacting the sludge with both oxygen and ozone and the primary goal of the study was to investigate the potential for improving sludge dewaterability.

ABSTRACT

A three month field demonstration study was conducted on the hyperbaric oxyozosynthesis process for sludge conditioning and stabilization at the Monroe, Michigan Metropolitan Area Wastewater Treatment Facility. The process involves contacting sludges, under pressure, and at reduced pH of 3 to 4, with oxygen and ozone for periods of up to three hours. A 0.76 m^3 hyperbaric oxyozosynthesis process pilot plant developed by International Wastewater Reclamation Technologies, Inc., was used during the study.

The primary objective of this study was to evaluate the process with respect to its effect on sludge dewaterability, as measured by the Buchner funnel specific resistivity test. The process had been demonstrated previously for sludge stabilization measured by bacteria destruction. The present study confirmed that advantage, also the ability to reduce odors.

The findings of the study indicate that the oxyozosynthesis process did not improve sludge dewaterability, but actually decreased dewatering characteristics somewhat. To achieve approximately similar dewatering characteristics, as measured by the Buchner funnel test, oxyozone-contacted sludges (with and without pH adjustment) needed greater doses of polymer conditioning than did plant raw sludge. Also, the oxyozosynthesis process did not achieve any significant reduction of sludge volatile solids or total chemical oxygen demand.

Comments received after completion of the project from Ozonics Corporation, who presently has license rights to the process, are included in the Appendix to the report.

This report was submitted in fulfillment of Cooperative Agreement No. CR 810765 by Monroe County, Michigan under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from August 1, 1983, to July 1, 1985, and work was completed as of July 1, 1985.

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ACKNOWLEDGEMENTS

This project was conducted under a cooperative agreement between the United States Environmental Protection Agency (EPA) and Monroe County, Michigan, through the Office of the Monroe County Drain Commissioner by Greenhorne and O'Mara, Inc., and HydroQual, Inc.

HydroQual was responsible for developing the testing program, directing and assisting in the field studies, analyses of the data, and preparing the report on the study results. Greenhorne and O'Mara was responsible for overall project management, on-site supervision of the pilot plant operations and conducting on-site testing, the analyses of incorporating the oxyozosynthesis process into the Monroe plant sludge handling system and preparation of the final report. International Wastewater Reclamation Technologies, Inc. provided their hyperbaric oxyozosynthesis pilot plant and was responsible for its operation and maintenance.

The Monroe Drain Commissioner provided the site at the plant and plant personnel to collect and deliver the sludge samples to the pilot plant. Chemical and biological analyses of samples were subcontracted to Canton Analytical Laboratories of Ypsilanti, Michigan.

Participants in the project included:

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SECTION 1

INTRODUCTION

Description of Study

The Hyperbaric Oxyozosynthesis process for sludge conditioning and stabilization was tested at the Monroe, Michigan Metropolitan Area Wastewater Treatment Facility. Primary, secondary and combined sludge samples were collected over a three month period, and tested in a 0.76 m^3 pilot plant reactor. The study was funded through a cooperative agreement between the U.S. EPA Water Engineering Research Laboratory, Cincinnati, Ohio and Monroe County, Michigan, through the Office of the Monroe County Drain Commissioner. The County had an interest in the process for possible use for sludge treatment to improve dewatering prior to land disposal.

Also cooperating on the study was International Wastewater Reclamation Technologies, Inc. (IWWRT), who marketed the process at that time. Comments on the project from Ozonics Corporation, who presently has license rights to the process, are included in Appendix A-9.

Objectives

The objectives of this pilot plant demonstration study were to:

1. Determine the effect of the hyperbaric oxyozosynthesis process on conditioning of primary, secondary, and combined sludges for dewatering.

2. To evaluate the sensitivity of the system to the major process parameters which influence the design, operation and economics of the process.

3. To assess the effect of the process on sludge stabilization (disinfection and reduction in volatile solids), and characteristics of the resultant filtrate from dewatering.

4. To obtain and define requirements for operation maintenance and design for a full scale system.

Oxyozosynthesis Process

The hyperbaric oxyozonation process[1,2] involves contacting sludge at ambient temperatures with an oxygen-ozone gas mixture under pressure. The

sludge is pretreated by screening and/or communition, and pH adjustment. The sludge is continuously recirculated and mixed into the gas phase of the reaction vessel into which the oxygen-ozone gas is injected. Retention in the vessel is in the order of one to three hours.

International Wastewater Reclamation Technologies, Inc. supplied the pilot plant used at Monroe County. One full scale oxyozosynthesis system, which processes 75.7 m^3/day (20,000 gpd) of primary sludge has been in operation since 1981 at West New York, New Jersey.[3] The pilot plant had been used previously in a study at the Washington Suburban Sanitary Commission (WSSC) plant on a secondary sludge,[4] to evaluate sludge stabilization (as measured by coliform reduction). Other sludges had also been tested with the pilot plant.[5]

Results of the West New York system have been reported.[3] The system effectively pretreated sludge prior to flotation and belt filter press dewatering, making it suitable for disposal in a landfill. The sludge was reported to be dewatered to a cake solids of over 40 percent. The sludge pH was adjusted to 3.5 to 4 and a reactor contact time of 60 to 90 minutes was found sufficient for optimizing filtrate quality, and cake solids. Acidification released metals from the sludge, and pathogens were destroyed in the oxyozosynthesis process. There was no discernable reduction in volatile solids; however, the sludge was reported to be relatively sterile, and not subject to subsequent degradation of organics and consequent odors.

At WSSC, the oxyozosynthesis pilot plant was operated on the waste activated and thickened waste sludge from the WSSC Western Branch Sewage Treatment Plant,[4] which is a two stage activated sludge plant, without primary sedimentation. The studies were primarily aimed at sludge stabilization. It was concluded that the process was an effective stabilization process. Operating conditions were held constant in the tests; pH 3 to 4, ozone at approximately 100 percent output, 0.18 g/l (16 gallons of sludge) and pressure, 412 kPa (60 psi). The time of ozone contact was normally 150 minutes. Two sludge concentrations, 2 and 4 percent were tested. Sampling was for total and fecal coliforms and Salmonella, chemical oxygen demand (COD), solids, heavy metals, nitrogen and phosphorus. It was concluded that neutralization of the contacted sludge prior to dewatering was necessary to improve dewaterability with polymers and to complex heavy metals solubilized in the process. Dewaterability was not degraded by the process; however, improvements in dewaterability were difficult to detect. Ozonated sludge was dewatered, using a belt filter press, to 21 to 24 percent solids at neutral pH and polymer dosage of 2.0 to 2.5 kg/dry metric ton (4-5 lbs/ton) of solids. Total solids and volatile solids reductions were found to be negligible as were nutrient release. Sulfide odors were non-existent at the end of the test. Heavy metals were solubilized. Salmonella and coliform reductions were essentially complete after two hours of contact. Both acid treatment and ozonation were considered responsible for pathogen reduction. Limited data presented[5] on several other pilot plant tests on various sludges from municipal and industrial plants indicated stabilization and dewaterability of the contacted sludges.

Monroe Metropolitan Area Wastewater Treatment Facility

Plant Description. The Monroe Metropolitan Area Wastewater Treatment Facility is a conventional secondary activated sludge treatment plant receiving wastewater from the City of Monroe and outlying areas. The plant, designed for 1.1 m^3/sec (24 mgd), currently treats about 0.57 m^3/sec (13 mgd) of wastewater from domestic and commercial sources, with little industrial input. There is, at times, a high stormwater input to the plant.

The plant is well operated with biochemical oxygen demand (BOD) and suspended solids removal in the 90 to 98 percent range. Effluent BOD averaged 7 mg/l and suspended solids 11 mg/l during the last half of 1983. Secondary sludge is wasted to the two primary clarifiers and the combined sludge is presently dewatered on vacuum filters. Polymer and a small amount of ferric chloride are added for conditioning. The filter sludge cake is dry mixed with lime for stabilization, and the stabilized sludge is hauled off to a land disposal site. Sludge processed is approximately 7.3 to 10.9 metric tons of dry solids per day. Approximately 50 percent of the sludge is primary and 50 percent secondary. Polymer usage varies from 20 g/kg to 36 g/kg dry sludge solids. Sludge concentration to the vacuum filter is typically 3 to 4 percent and the sludge cake produced is about 13 percent solids. Table 1 summarizes plant sludge data and characteristics of samples of sludge cake. A potential need for alternate sludge disposal sites and cost reductions motivated studies on sludge handling and disposal. The plant had under consideration use of belt filter presses for dewatering, and was interested in the oxyozosynthesis process for sludge stabilization and possible enhancement of dewatering characteristics.

Preliminary Oxyozosynthesis Testing

Preliminary testing was conducted at Monroe by IWWRT in February and March 1983.[4] Ten trial runs were made over a two week period. Apparently, there were equipment problems which negated several runs. New equipment was installed, and piping changes were made. The results confirmed the process ability to reduce coliform bacteria and eliminate odors after about 90 minutes of treatment. Results, with respect to dewatering, were not as successful as had been hoped. The pH had to be raised to neutral before conditioning chemicals would work, and sludge cake results were poor compared to past oxyozosynthesis results. The belt filter press blinded with the sludges tested. The study was quite limited in collection of pertinent data and information and left many questions to be further evaluated in subsequent testing. It was valuable, however, since equipment deficiencies were rectified and some indications of results to be expected, were obtained.

TABLE 1. MONROE WASTEWATER TREATMENT PLANT AVERAGE SLUDGE CHARACTERISTICS
(June to December 1983)

Operations Data	
Sludge to filter total solids percent	3.4
Polymer g/kg dry solids to filter	27.0
Ferric chloride g/kg dry solids to filter	1.6
kg dry solids/day (June to December 1983)[a]	6170.0
Sludge cake percent total solids	13.2
Percent volatile solids	48.6

Sludge Analysis[b]	mg/kg Dry Solids
TKN	34,000
Total nitrogen	31,400
Ammonia-N	2,570
Phosphorus	14,100
Arsenic	10
Cadmium	3.5
Chrome	62.3
Lead	90
Copper	90
Nickel	270
Zinc	1,140
Potassium	1,720

[a] 9270 kg per dewatering facility operating day
[b] From analyses of 15 sludge cake samples 6/83 to 2/84

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

1. The hyperbaric oxyozosynthesis process for sludge conditioning, tested on the sludges produced at the Monroe, Michigan, Metropolitan Area Wastewater Treatment Facility, had no significant beneficial effect on improving the dewaterability of the primary, secondary (waste activated sludge) or combined sludges.

2. The major process variables, pH, ozone, contact time, operating pressure and gas mode were investigated. The results did not indicate that any of the variables had a consistent and significant effect on improving sludge dewaterability, although, in general, oxyozonated sludges exhibited somewhat poorer dewatering characteristics than the raw sludges tested.

3. Polymer conditioning, used at the Monroe plant in conjunction with vacuum filtration dewatering, was required to obtain dewaterability characteristics on oxyozone contacted sludges, equivalent to polymer treated raw sludges.

4. Optimum polymer requirements for contacted sludges were higher by about 40 to 60 percent than for raw sludges to achieve comparable dewaterability characteristics.

5. Adjustment of pH of the oxyozonated sludge from a pH of 3 to 4 to a pH of 6 to 7 increased dewaterability characteristics both with and without the use of polymer conditioning chemicals.

6. Acidification of the raw sludges to a pH of 3 to 4 improved dewaterability characteristics (without polymer addition) to a slight degree. Acidification also effected a substantial reduction in fecal coliform concentration. Subsequent oxyozonation for 60 minutes reduced coliform levels to generally < 10 MPN/100 ml.

7. Measurements of total COD and total and volatile solids on raw and oxyozonated sludges indicated that the process did not significantly reduce any of these constituents. Some solubilization of COD, determined by a measured increase in filtered COD after oxyozonation, was observed.

8. Soluble BOD was reduced, and soluble phosphorus was increased by oxyozonation of the sludges. The effect of oxyozonation on the soluble

total Kjeldahl nitrogen (TKN) and ammonia nitrogen concentrations in the sludge was variable with both increases and decreases measured. Acidification of the combined sludge resulted in the solubilization of iron; however, subsequent ozonation reduced the soluble iron concentration. Soluble zinc concentration was increased in the process. Chrome, lead and copper were in very low concentrations in the filtrates for raw sludge samples, and were not measurably affected by the oxyozosynthesis process in these studies.

9. Consumables for the process, operated as suggested by the pilot plant study results, were determined; however, they could not be optimized based on dewaterability criterion.

10. Based on the results of these investigations, it does not appear that the process is suitable for sludge conditioning for dewatering purposes.

11. The process does, however, stabilize sludges as measured by reduction in fecal coliforms and by obvious odor reduction. It is recommended, therefore, that the process be considered for sludge stabilization; however, optimization of operating conditions, and chemical, and power usage is required for this application.

12. The use of the oxyozosynthesis process for heavy metals removal from highly contaminated sludges, in addition to sludge stabilization, may be practical. Further studies would be required to optimize the pH for heavy metal solubilization, and subsequent dewatering, and filtrate treatment or disposal.

13. The present worth process unit cost of the hyperbaric oxyozosynthesis process at the Monroe, Michigan Metropolitan Area Wastewater Treatment Facility is estimated to be at $230/metric ton dry solids processed.

SECTION 3

EXPERIMENTAL PROGRAM

The experimental program was finalized prior to the project startup in conjunction with U.S. EPA project personnel and IWWRT. The primary objective of the study was to determine the process performance based on contacted sludge dewaterability compared to non-contacted sludge. The test program included evaluation of primary and secondary sludges as well as the combined sludge currently dewatered at Monroe.

The Buchner funnel resistivity test was used as the measure of dewaterability. Disinfection of the sludge to a substantial degree by the process had been demonstrated at other locations;[3,4] thus, only limited testing to confirm coliform reductions was done on a number of runs during the program. The program was designed to be flexible, and as results were analyzed, the testing schedule was modified, as appropriate, to avoid unnecessary testing, and to permit appropriate emphasis on the more important variables. A total of 62 runs were conducted on sludge samples, utilitizing the IWWRT (0.76 m^3) pilot plant.

Process Variables

The planned initial series of runs were conducted to determine the ability of the process to improve sludge dewaterability and the effect of process variables. Process parameters relevant to a system design include the variables shown in the listing below.

The practice at the Monroe plant was to waste secondary sludge to the primary clarifiers (two shifts/day) and to pump the combined primary and secondary sludges to a sludge well prior to dewatering. Initially, primary sludge was obtained by directing a portion of plant influent flow to a spare grit chamber to allow equivalent primary settling. The sludge was pumped to 208 liter (55 gallon) containers for use in the pilot plant. For later runs 31 to 39, primary sludge was obtained from a primary clarifer. During the secondary sludge wasting period to the primary clarifiers, the influent to this clarifier was closed, thus isolating the clarifier from secondary waste sludge. Secondary sludge was obtained from the secondary clarifiers return sludge pumping. Generally, it was necessary to thicken secondary sludges in 208 liter (55 gallon) drums to obtain samples in the 1.5 to 2 percent solids concentration range desired. Combined sludges were collected from the primary clarifiers during pumping to the sludge wet well preceding dewatering.

Variables	Typical Range of Variables[a]
Sludge types	primary, waste secondary, combined
Solids concentration	1 to 6 percent
pH	2.5 to 6.0
Ozone utilization rate (at constant pressure)	0-0.23 g/l (0-0.2 #/100 gallons)
Contact time	30 to 120 minutes
Contact pressure	138 to 412 kPa (20 to 60 psi)
Oxygen utilization rate (related to contact time)	3.6 to 14.4 g/l (3 to 12 #/100 gallons)

[a]Based on pilot plant equipment specifications and previous studies by IWWRT and others.[1,4,6]

The initial series of runs centered about the variables on the optimum conditions estimated for the process. Runs were conducted on the primary sludge, waste activated sludge, and the plant combined sludge. The major variables of pH, ozone utilization, and time were evaluated. A series of runs, 31 to 39 (primary sludge) and 40 to 43 (combined sludge), were conducted varying pressure and modes of operation. The final series of pilot plant tests runs 50 to 59 were conducted under optimized operating conditions on combined sludge samples produced at Monroe. During this phase, the effect of the process on dewaterability, polymer, and pH requirements for dewatering were compared with the combined raw uncontacted Monroe sludge.

Several run conditions were repeated and are designated 0 tests. Table 2 outlines the testing program conducted.

TABLE 2. PILOT PLANT TESTING PROGRAM

Runs	Sludge	Variable	Constants
1-5	primary	pH	O_3, O_2, pressure at maximum
6-10	secondary	pH	O_3, O_2, pressure at maximum
11-15	primary	O_3	pH 3 to 4, O_2, pressure at maximum
16-20	secondary	O_3	pH 3 to 4, O_2, pressure at maximum
21-25	combined	O_3	pH 3 to 4, O_2, pressure at maximum
26-30	combined	pH	O_3, O_2, pressure at maximum
31-39	primary	pressure or O_3	O_3, O_2, pH 3 to 4
40-43	combined	O_3	No initial pressurization
50-59	combined	pressure/time	pH 3.5, O_3, replicate runs
60-61	combined	gas relief mode	pH 3.5, O_3
00-01	combined	pH	repeat runs
06-09	secondary	-	repeat runs

Table 3 outlines the analytical program on samples of raw and contacted sludge.

TABLE 3. ANALYTICAL SCHEDULE

Group	Test Analyses	(RS) Raw Sludge	(AS) Acidified Sludge	(CS) Contacted Sludge(s)	Sludge Cake(s)	Filtrate[a]	Run Number
A	TS	X		X	X		
	TVS	X	X	X	X		All
	pH	X	X	X		X	Runs
	Alk/Acid	X		X			
B	COD_{Tc}[b]	x		x			All
	COD_F	X	X			X	Runs
C	BOD_T	X		X			12
	BOD_F	X				X	Runs
D	TKN	X		X			
	TKN	X				X	
	NH_3-N	X	X			X	12
	Total P	X		X		X	Runs
	Total P-F	X	X				
F	Coliforms	X	X	X			38[d] to 43 50, 51 57 to 61
G	Buchner Funnel Test	X	X	X[e]			All Runs

[a] From Buchner funnel test
[b] T-Total
[c] F-Filtrate from sample
[d] Coliform data on initial runs discarded laboratory error
[e] Contacted sludge (Buchner funnel run on 3 samples)

Description of Pilot Plant

The oxyozosynthesis mobile unit was located in a maintenance storage building at the Monroe Treatment Plant. Figure 1 is a schematic diagram of the pilot plant and Figures 2 and 3 are two views of the pilot plant at Monroe.

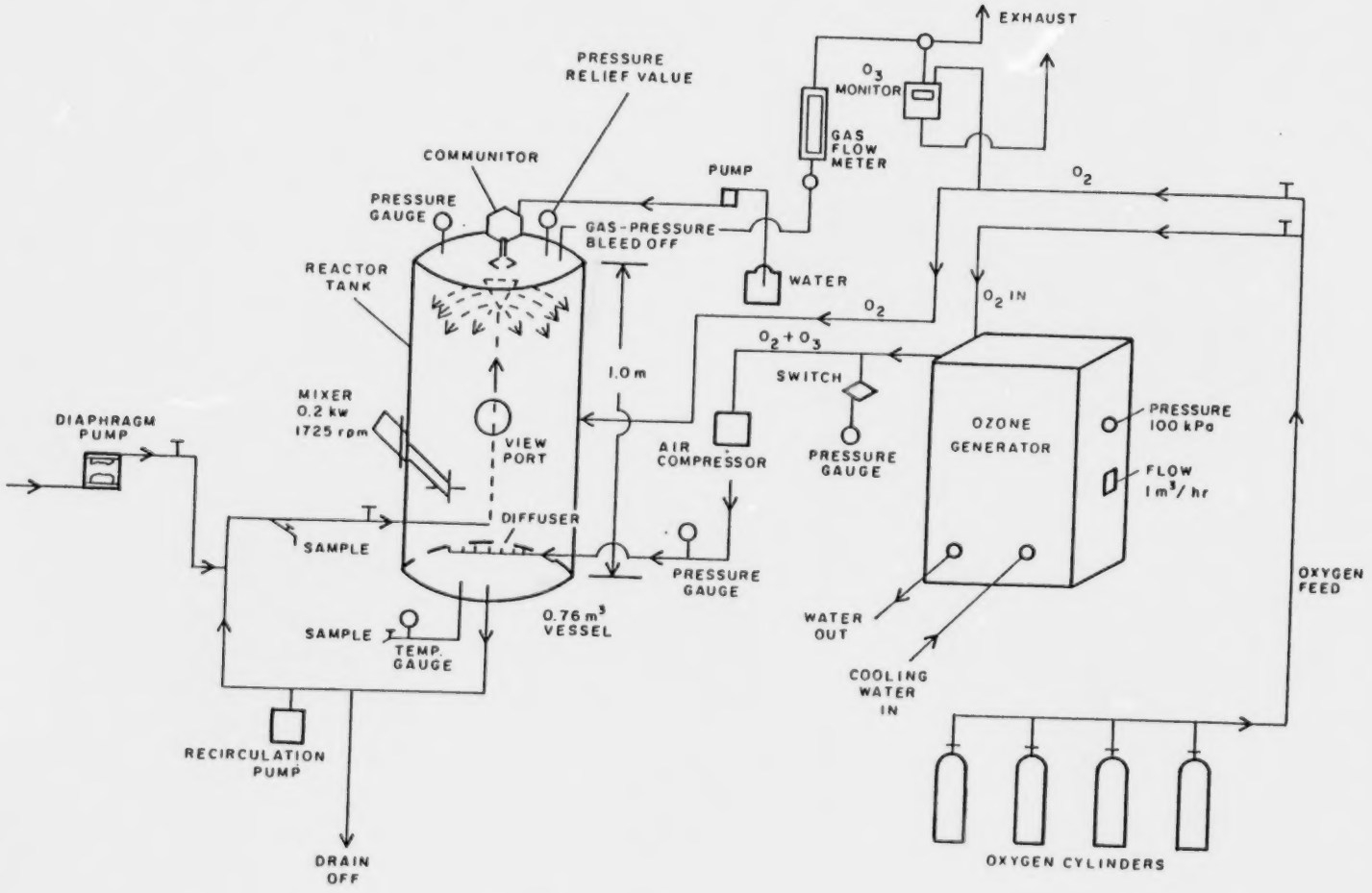


FIGURE 1. SCHEMATIC DIAGRAM HYPERBARIC OXYOZOSYNTHESIS PILOT PLANT

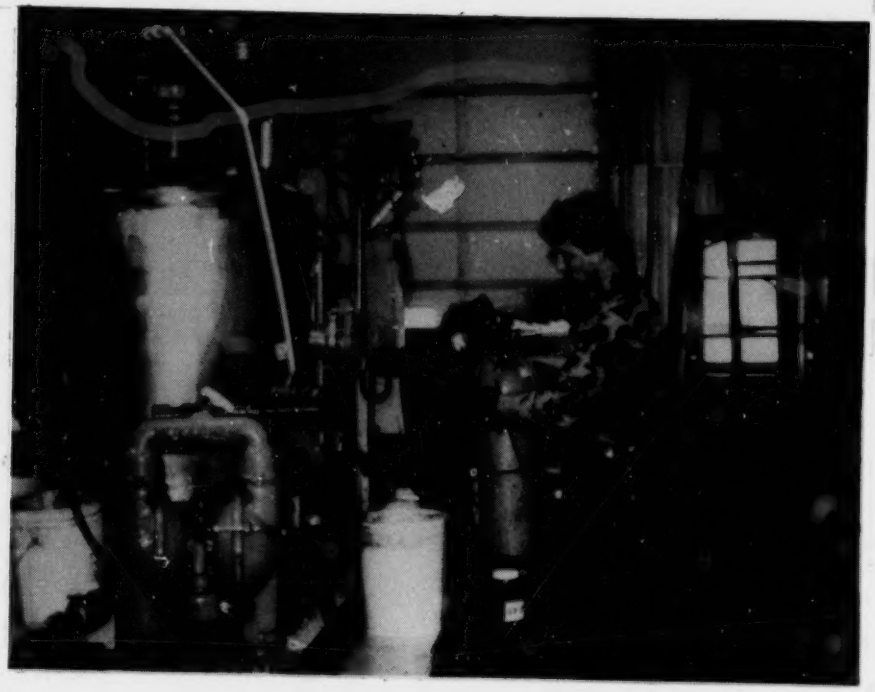


FIGURE 2. PILOT PLANT--FRONT VIEW

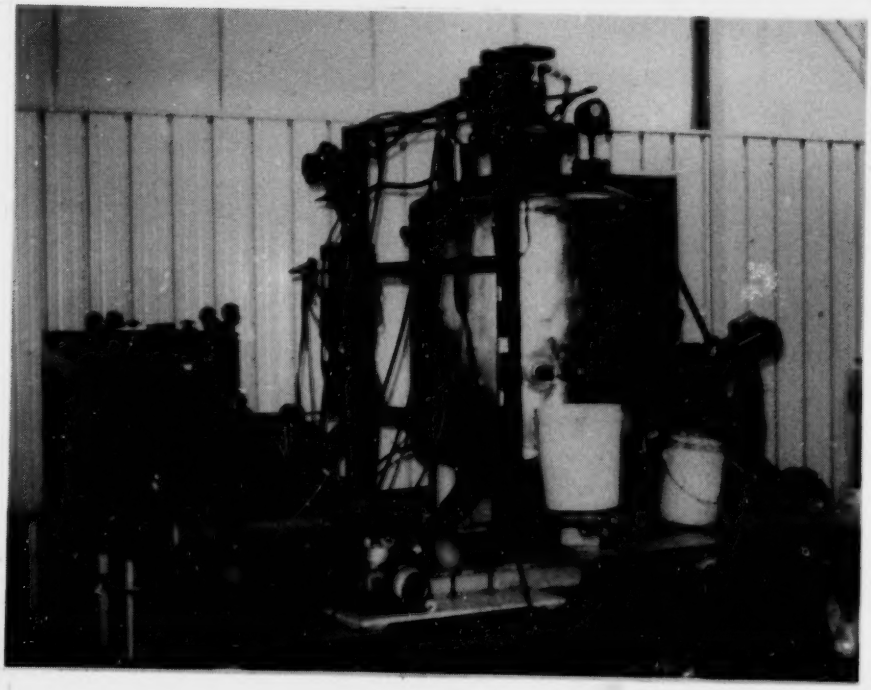


FIGURE 3. PILOT PLANT--SIDE VIEW

The pilot plant was constructed on an 2.4 by 3.7 meter (8 by 12 foot) trailer. The major component of the pilot plant was a 0.76 m^3 (200 gallon) stainless steel reactor vessel containing a side entry mixer, a top entry mixer-communitor, and a gas diffuser. Connections to the vessel were provided for sludge filling and draining, sludge recirculation by a Jabsco 0.76 lps (12 gpm) pump with a 0.4 kW (1/2 hp) motor, gas injection, gas exhaust and sampling.

An ozone generator (Model G-1) from PCI Ozone Corporation rated at 1.1 kg (2.5 lbs) ozone daily, and an ozone/oxygen gas compressor (KNF Newborger) were mounted on the trailer. A cooling waterline was connected to the ozone generator which was fed oxygen gas. A 1.5 kW (2 hp) air compressor provided operating air for a positive displacement bellows type influent pump, which was used to pump sludge into the reactor. Oxygen was supplied as gas from cylinders, and a continuous ozone monitor to measure ozone in the gas feed to the reactor was mounted on the wall adjacent to the pilot plant. A stainless steel flotation tank of about 0.38 m^3 (100 gallons) capacity, to receive contacted sludge, was provided with the pilot plant. Some 208 liter (55 gallon) drums were used to collect sludge samples. Secondary sludge samples were thickened in the drums and composited to additional drums. A drum mounted mixer was used to mix acid and sludge to adjust the pH to desired levels prior to pumping sludge into the reactor.

Pilot Plant Operations

Primary and combined plant sludges were collected and delivered to the pilot plant area by Monroe plant personnel shortly before the trial run. Secondary sludges were collected 8 to 16 hours prior to a trial run to permit thickening to desired sludge concentrations of 1.5 to 2.0 percent. Greenhorne & O'Mara personnel supervised the pilot plant operations, and collected and tested samples; IWWRT personnel operated and maintained the pilot plant. HydroQual personnel assisted in sampling and testing during several visits to the site, in addition to analysis of data and directing the overall program.

A sample of the collected sludge was titrated with one normal sulfuric acid, and the required full strength acid required to adjust the pH of the 375 liter (100 gallons) of sludge, was calculated. Typically, more acid had to be added to the sludge than was determined by the titration test due to a gradual reaction of the acid with the sludge. Acid requirements are discussed in Section 4, Study Results. The objective was to achieve the desired pH, within about 0.5 pH units in the contacted sludge at the end of the run.

Approximately 375 liters (100 gallons) of pH adjusted sludge was then pumped into the closed reactor vessel. This resulted in a pressure increase in the vessel to about 124 to 138 kPa (18 to 20 psi). On selected runs, towards the end of the study, this pressure was released; however, on most of the runs it was not. The recycle pump and mixer, and comminuter were put into operation, and oxygen was admitted to the reactor vessel until a pressure of 275 kPa was achieved. This required 3 to 5 minutes. On selected designated runs the pressure level was varied.

Oxygen was then fed to the ozonator at a rate of 0.8 m^3/hr (28 cfm) at 100 kPa (15 psig). The ozonator control was preset to the desired ozone percent output, from 0 to 100 percent of capacity. The oxygen ozone mixture was compressed and injected into the reactor. A pressure relief valve on the reactor was set at 412 kPa (60 psi). When the pressure in the reactor reached 412 kPa (60 psi) (about 25 to 30 minutes after starting the ozonator), the gas was exhausted to atmosphere through a control valve and gas flow rate rotometer. The gas flow measured was about 38 cfh at atmospheric pressure.

A tiny side stream of the gas fed to the reactor was diverted to the ozone monitor, and in several runs off gas from the reactor was also monitored. The ozone content of the gas was about 2.3 percent at the ozonator setting of 100 percent output. Measurements indicated that actual output of the ozonator at 100 percent setting, was approximately 172 kg/d (1.6 lbs/day). Oxygen utilization was determined by a gage on the cylinders. The average oxygen feed rate to the ozonator was measured as 0.2 m^3/h (33.6 cfh) at 15 ^oC, and atmospheric pressure.

The system was operated for the desired time, and contacted sludge samples were collected at several time intervals, typically 30, 90 and 150 minutes after 412 kPa (60 psi) was attained in the reactor. At the conclusion of the run, the sludge was exhausted to the float tank or to a plant sewer, and the reactor was flushed with plant water in preparation for the next run.

Figure 4 illustrates the typical operating cycle used for most of the runs. This cycle is basically the cycle normally recommended by IWWRT, and had been utilized in other studies on the process.[4] Other operating and test conditions were tested during certain runs, and included: variable ozone rate; operation at lower pressures of 138, 207, and 275 kPa (20, 30, and 40 psi); the elmination of the oxygen pressurization step and the initiation of the ozone and oxygen mixture feed immediately after filling the unit; stopping the addition of ozone and oxygen after reaching 412 kPa (60 psi) pressure, but continuing recycling and mixing; and an intermittent cyclic bleed off of gas from 441 to 386 kPa (64 to 56 psi). The results from testing under these conditions are discussed in Section 4, Study Results. Data were collected during each run and recorded on standard data sheets. A typical data sheet is included in the appendix, along with data summaries.

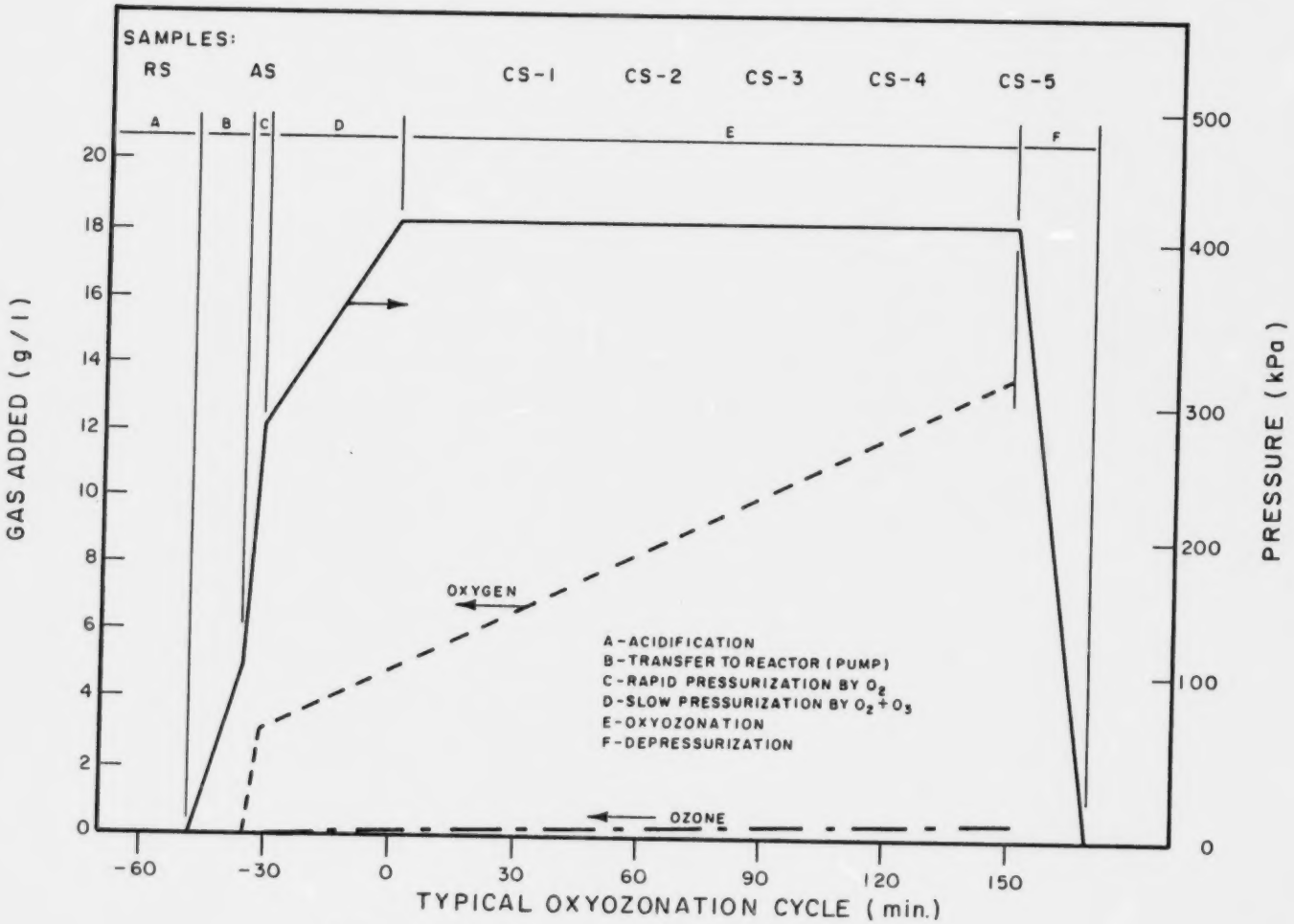


FIGURE 4. PILOT PLANT TYPICAL OPERATION CYCLE

SECTION 4

STUDY RESULTS

Buchner Funnel Analysis

The Buchner funnel specific resistivity test was used to measure dewaterability characteristics. The specific resistance (r) of sludge samples was determined using the apparatus and procedure described in the Appendix. The general equation used to determine specific resistance is:

$$r = \frac{2PA^2b}{\mu w}$$

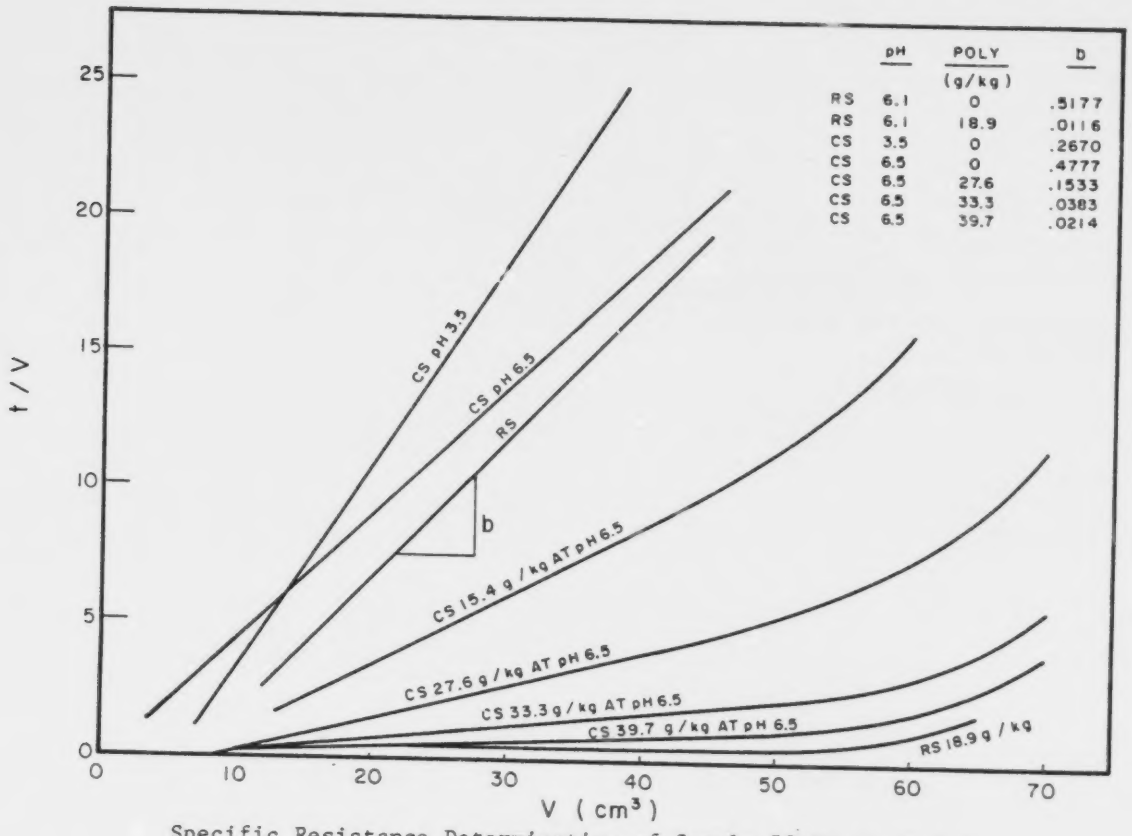
r - specific resistance (cm/g)
P - vacuum pressure (dynes/cm^2)
b - relative specific resistance slope of t/V versus V plot (sec/ml^2)
w - mass dry solids per unit filtrate volume (g/cm^3)
A - filter area (cm^2)
μ - viscosity (poise)
t - filtration time (sec)
V - filtrate volume (cm^3)

Figure 5 illustrates typical plots of V versus t/V to determine relative specific resistance. An example of the calculation of specific resistance for sample 59 RS is shown.

A number of sludge samples were run in duplicate to determine the variability of results in the Buchner funnel tests. These results are summarized below using the industrial statistic value, i, which is the percent deviation of the samples from the mean.

BUCHNER FUNNEL TEST-DUPLICATE SAMPLES

	Average i %	Standard Deviation f_i	Number of Pairs
Raw sludge samples	3.7	2.6	7
Contacted sludges	4.2	2.7	7



Specific Resistance Determination of Sample 59 RS at pH 6.1

$A = 63.61\ cm^2$
$P = 1.0342 \times 10^6$ Dynes/cm^2 (15 psi)
$\mu = 0.0114$ poise at 15°C

$b = 0.5177\ sec/ml^2$

Sample Size = 0.1 liters
Sample TS = 4.59% (45.9 g/l)
Filtrate Volume = 45 cm^3
Cake wt = 40.9 g

$$w_3 = \frac{45.9\ g/l\ (0.1\ liters)}{45\ cm^3} = 0.1020\ g/cm^3$$

$$w_1 = \frac{40.9\ g}{45\ cm} = 0.0920\ g/cm^3$$

$$r_3 = \frac{2PA^2b}{\mu w} = \frac{2\ (1.0342 \times 10^6)(63.61^2)(0.5177)}{0.0114\ (0.1020)} = 37.3 \times 10^{11}\ \frac{cm}{g}$$

$$r_1 = \frac{2\ (1.0342 \times 10^6)(63.61^2)(.5177)}{0.0114\ (.0920)} = 41.3 \times 10^{11}\ \frac{cm}{g}$$

Note: r also can be expressed in sec^2/g (divide cm/g by 980.6 for sec^2/g)

FIGURE 5. TYPICAL BUCHNER FUNNEL DATA PLOT V VERSUS t/V

The results for the sludge were quite close; thus, variability due to the Buchner funnel test was relatively low.

In the calculation, w, which is the mass of cake solids per cubic centimeter of filtrate; three values were determined. The first value (W1) was based on actual measurement of the weight of the cake filtered from the sample. The second value (W2) was based on the solids concentration measured in the raw sludge sample, and the weight of sample (raw and contacted) used in the test. The third value (W3) was based on the raw sludge sample solids concentration and the volume of the sample (raw or contacted) used. The first method was considered the most accurate and was generally used in most of the data plots and analysis. The third method, the least accurate, particularly for contacted sludges which contained varying amounts of entrained air, thus, less weight per unit volume, had to be used for several sets of data, since some or all cake solids samples could not be determined, due to poor filtrability, and a "soupy" cake, which precluded, obtaining a cake sample. Table A-2 in the Appendix includes the specific resistance value calculated for each method.

Process Variables Effect on Dewaterability

In accordance with the planned program, the first several series of pilot plant runs centered on an evaluation of the effect of the major process variables, pH, ozone, time of contact, and pressure on each of the three types of sludge produced at Monroe: primary, secondary, and combined. The typical operating sequence previously described was used for these runs.

Figure 6 presents the results for primary sludge which was collected from the grit chamber. Specific resistance of contacted sludge samples is compared to pH and to percent of ozone output of the ozonator (see Appendix), for samples collected after 30 minutes of ozonation at 412 kPa (60 psi), CS-1, after 90 minutes, CS-3, and after 150 minutes, CS-5. The specific resistance of the raw primary sludge, prior to pH adjustment and ozone contact, which was used in each run, is shown for comparison. A number of observations based on these results can be made:

1. Specific resistance values after oxyozonation were higher than the raw sludge values, indicating a reduction in dewaterability.

2. Cake solids listed for each run were generally lower for sludge samples after oxyozonation.

3. Time of ozonation, CS-1 at 30 minutes to CS-5 at 120 minutes at 412 kPa (60 psi), appeared to increase the specific resistance of the sludge to a slight degree.

4. The pH, based on runs 1 to 5, appeared to be optimized at about pH 5 with respect to specific resistance values, although specific resistance at pH values of about 2, 3, and 6.5 are fairly similar for these runs and are similar to results in runs 11 to 15 at pH 3.1 to 3.7.

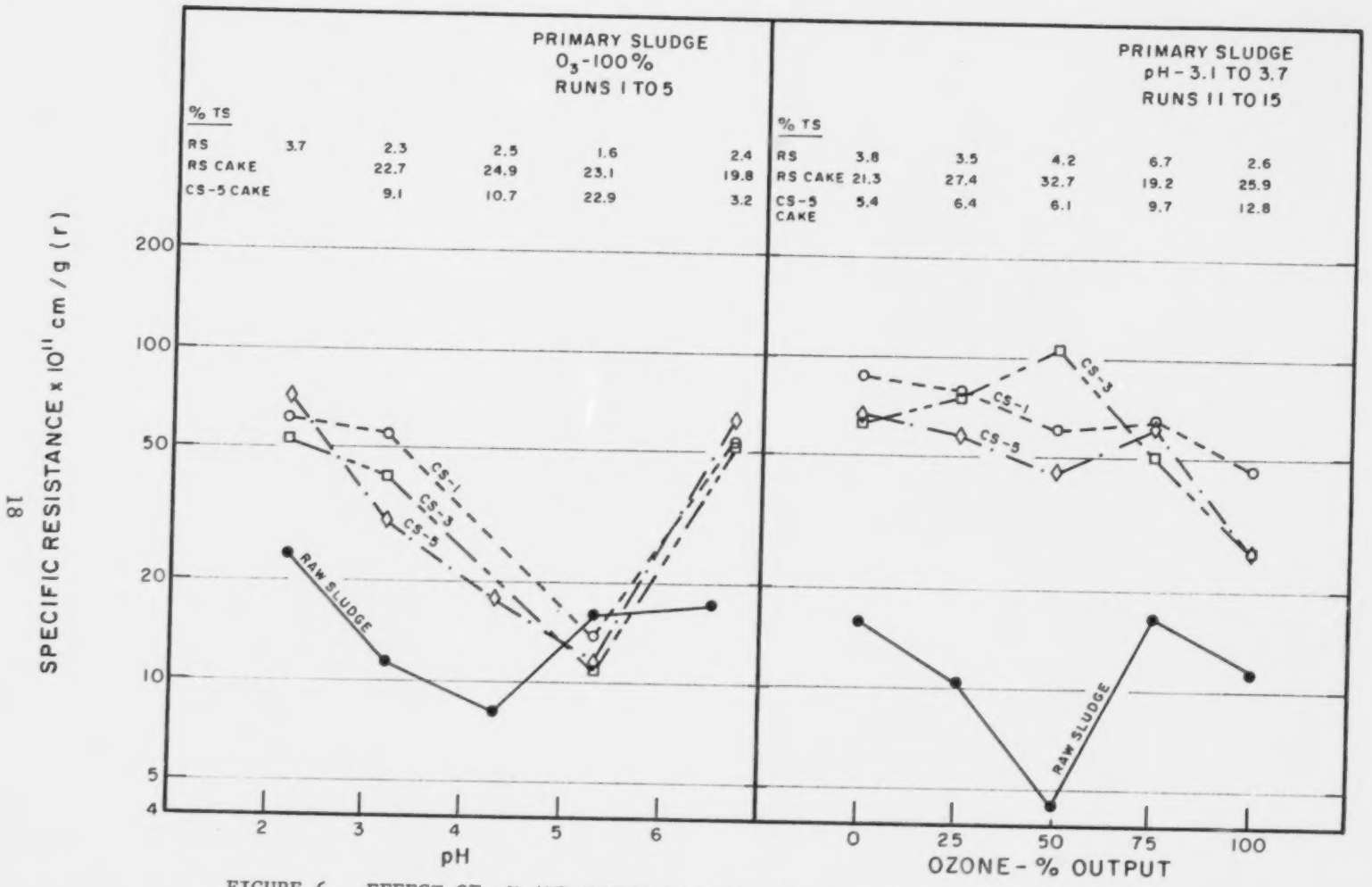


FIGURE 6. EFFECT OF pH AND OZONE ON SPECIFIC RESISTANCE--PRIMARY SLUDGE

5. The amount of ozone used in the test appeared to have little effect on specific resistance although a slight trend of decreasing specific resistance from 0 percent to 100 percent of ozonator capacity was observed. This trend may be due to raw sludge characteristics and variability in test results.

Figure 7 illustrates results comparing specific resistance with process variables for secondary (waste activated sludge) samples. Observations made based on these results include:

1. Specific resistance values were generally higher after oxyozonation.

2. Cake solids data indicated both lower and higher results for oxyozonated sludge samples compared to raw samples. Cake solids were highest on contacted sludges at pH of about 3 and ozone output setting of 75 to 100 percent.

3. Time of ozonation generally appeared to increase the specific resistance of the sludges. Data for specific runs, however, indicated some variation from this trend.

4. The adjusted pH, based on runs 06 to 10 appeared to be optimized at about pH 4; however, results from runs 16 to 20 at pH 3.4 to 3.9 were similar to results at pH values of 3, 5, and 6.

5. The amount of ozone applied did not affect specific resistance significantly. The trend of higher specific resistance as ozone output increased appeared to be related to the raw sludge specific resistance which showed a similar increasing trend.

Figure 8 illustrates results comparing the effect of process variables on the specific resistance of the combined plant sludges. These samples were randomly collected on test days, with no regard to the plant operational schedules for sludge wasting and pumping. The raw sludges show remarkable uniformity in specific resistance values for the 13 runs illustrated. Observations which can be made include:

1. Specific resistance values were generally higher for the contacted sludges. The differences between raw and contacted sludges did not appear to be as great as was observed with the primary and secondary sludges.

2. Buchner funnel filter cake solids for both raw and contacted sludges were quite similar, with slightly lower values generally seen with the contacted sludges.

3. Time of ozonation did not appear to have an effect on specific resistance. Results from runs 21 to 25 were fairly similiar to the results for the primary sludge.

4. The sludge pH, from about 6.2 (no adjustment) to 2.2, did not appear to have a clear, significant effect on specific resistance. The data from

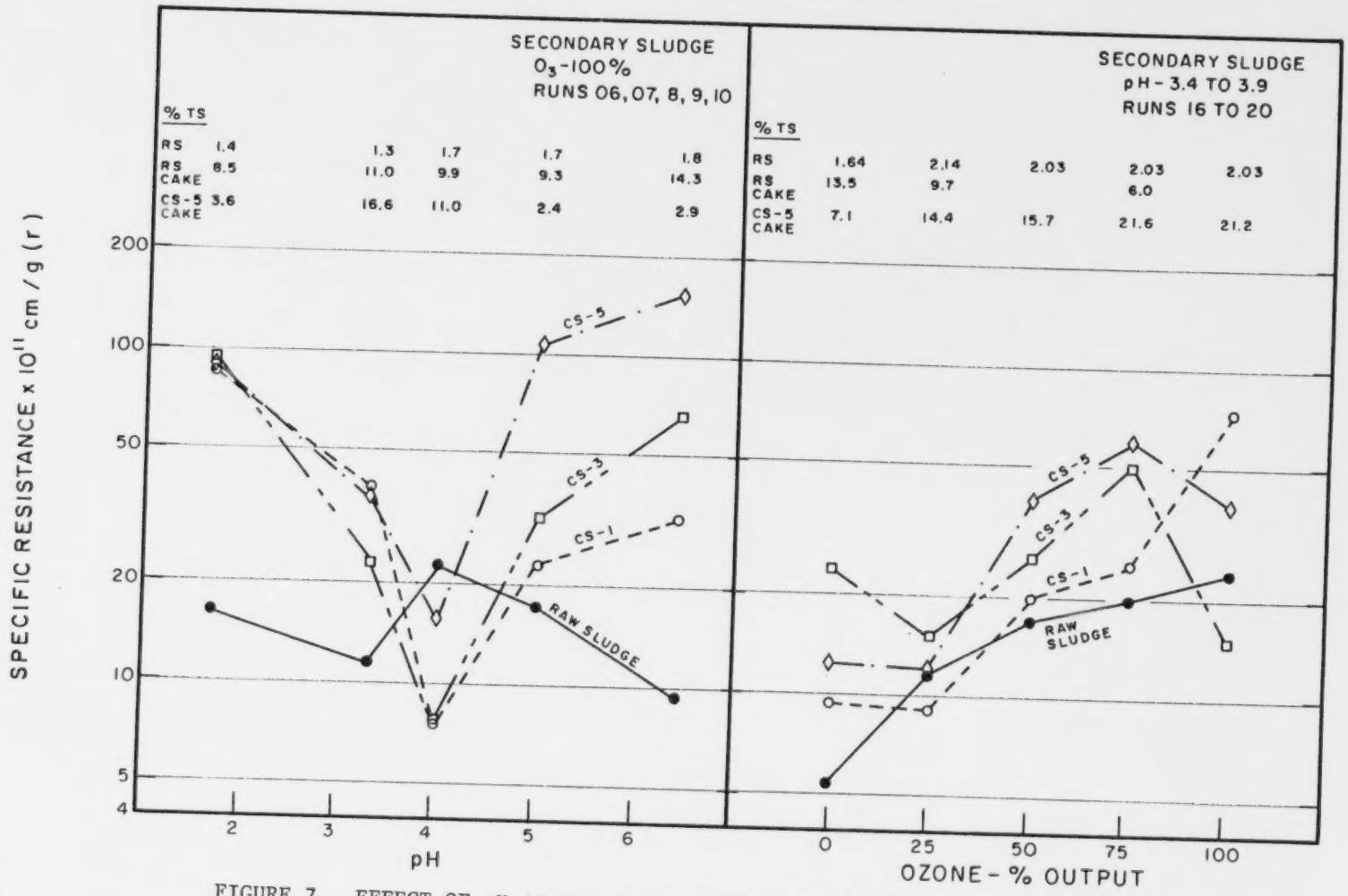


FIGURE 7. EFFECT OF pH AND OZONE ON SPECIFIC RESISTANCE--SECONDARY SLUDGE

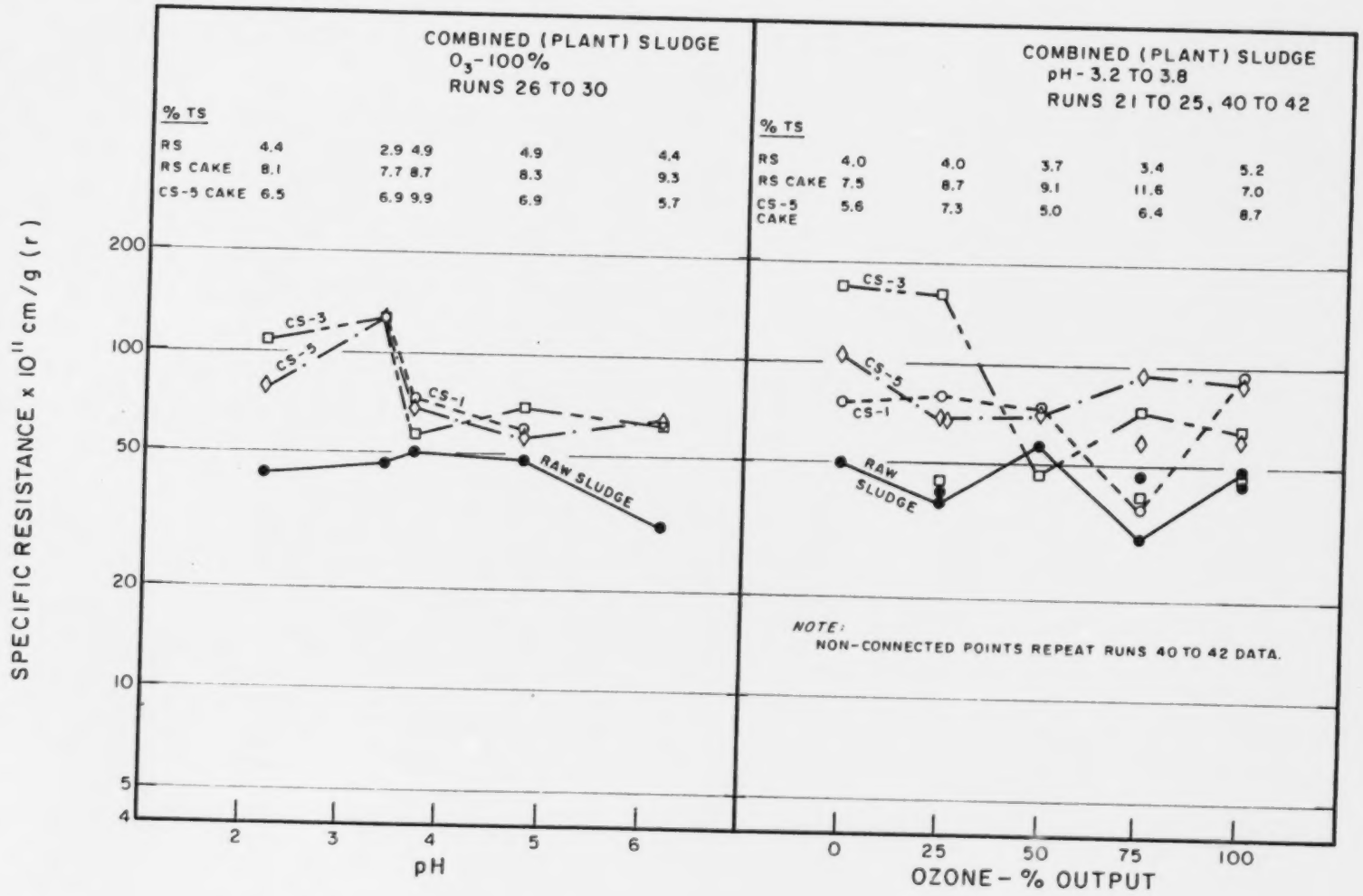


FIGURE 8. EFFECT OF pH AND OZONE ON SPECIFIC RESISTANCE--COMBINED SLUDGE

runs 26 to 30, tended to indicate a possible effect at pH values of about 3.5 and greater. However, the range of specific resistance for runs 21 to 25 at pH 3.2 to 3.8, were about 40 x 10^{11} to over 150 x 10^{11} cm/g and were greater than the values obtained in runs 26 to 30.

5. The amount of ozone applied did not appear to have any effect on specific resistance of the contacted sludges. Results from several runs from later in the study (runs 40 to 42), in which ozonated oxygen (at 25, 75 and 100 percent) were fed to the reactor during the pressurization mode were included on the figure. The results were essentially the same.

Figure 9 illustrates the effect of operating pressure on contacted sludge dewaterability. The oxyozonation process was designed by the inventor for operation at 412 kPa (60 psi). Several runs were conducted at lower pressures on primary sludge and combined sludge samples. In these runs, pH was adjusted to the 3 to 3.5 range and ozone applied at 100 percent. The average and range of results from replicate runs at the same conditions for runs 50 to 59 are shown on the plant combined sludge in Figure 9. Observations from the results of these studies include:

1. There appears to be a slight trend, although not entirely consistent, of increased specific resistance with increasing operating pressure for both sludges tested.

2. The contacted sludge cake solids were typically lower for the primary sludge and slightly higher for the combined sludge; however, operating pressure did not appear to have any significant influence on cake solids.

Figure 10 illustrates the results of specific resistance measurements determined on a sample of raw primary sludge from the primary clarifier (used in run 34). The sludge was adjusted with sulfuric acid to various pH levels and was not contacted with ozone. The results show a range from 17 to 35 x 10^{11} cm/g specific resistance generally in the range of raw sludge samples, Runs 31 to 36 shown on Figure 9. The data from this test indicated that a decrease in sludge specific resistance was achieved by adjusting pH to the 3 to 4 range. A comparison of average results of specific resistance, before and after acid pH adjustment for primary and combined sludges, is shown below:

Run Number	Sludge	Specific Resistance x 10^{11} Raw	Specific Resistance x 10^{11} pH Adjusted	Adjusted pH
31-39	Primary	29.9	28.4	2.7-3.3
41-42, 50-59	Combined	39.3	19.2	3.3-3.5

These results indicate that acid adjustment to pH 3 to 3.5 of the combined sludge reduced the specific resistance.

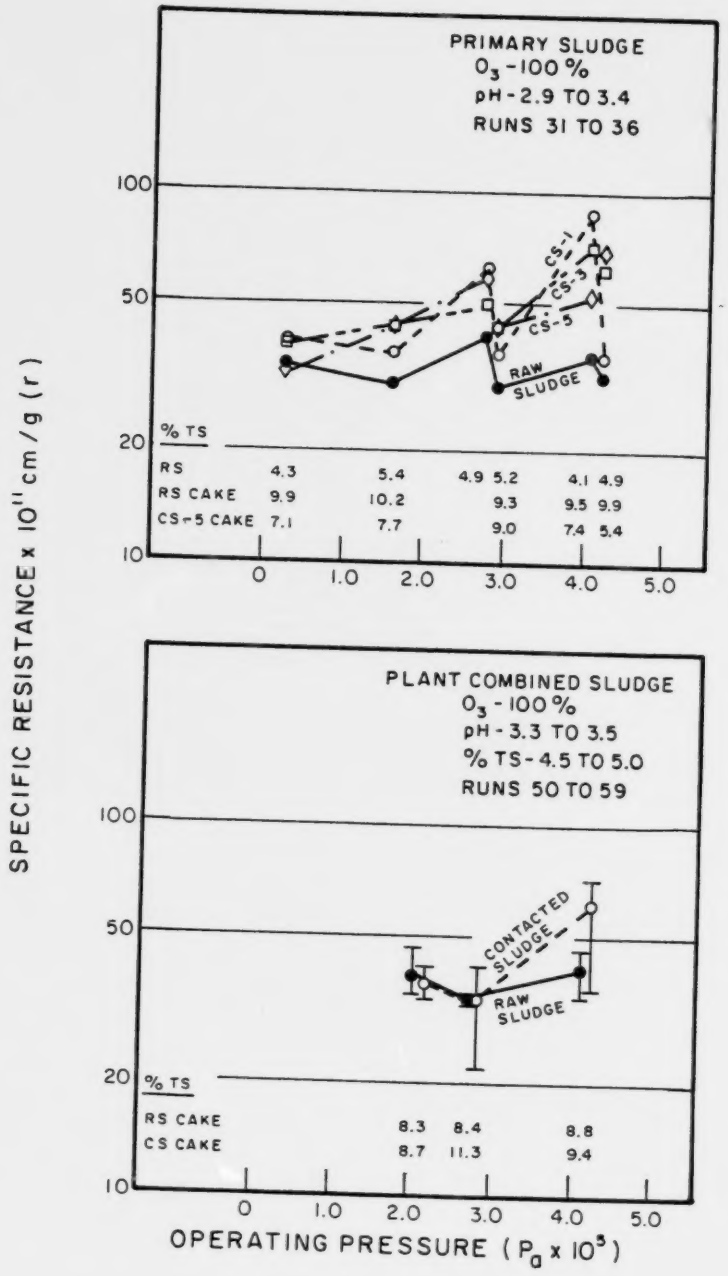


FIGURE 9. EFFECT OF OPERATING PRESSURE ON SPECIFIC RESISTANCE--PRIMARY AND COMBINED SLUDGE

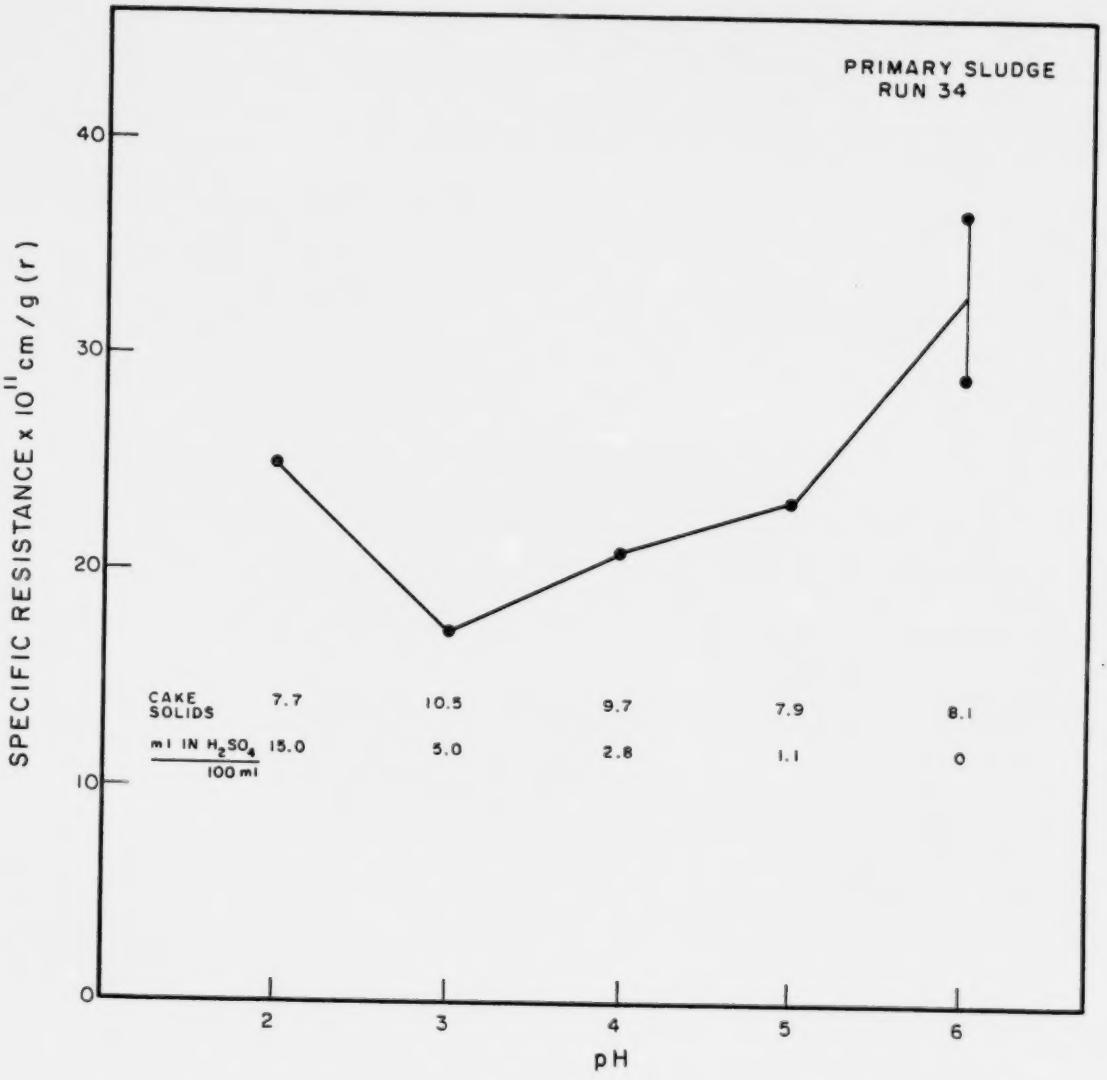


FIGURE 10. EFFECT OF ACIDIFICATION ONLY ON PRIMARY SLUDGE SPECIFIC RESISTANCE

Table 4 summarizes the specific resistance values and Buchner funnel cake solids determined on the raw sludges tested and on the contacted sludges after 150 minutes at 412 kPa (60 psi). All contacted sludges are included in this summary except those which had no pH adjutment or were not contacted with any ozone at all. Observations made from the summary data include:

TABLE 4. COMPARISON OF SPECIFIC RESISTANCE AND FILTER CAKE SOLIDS FOR SLUDGES TESTED

Raw Sludges				
	Specific Resistance X 10^{11}	Average $\bar{x}$	σ	n
Primary - Grit Tank	5.5 to 16.4	11.9	4.5	5
Primary NW Primary *	30.1 to 40.7	34.1	3.4	9
Combined	29.8 to 51.4	40.8	6.2	25
Secondary	7.4 to 40.4	15.4	9.8	10
	B.F. % Cake Solids	$\bar{x}$	σ	n
Primary - Grit Tank	19.2 to 27.4	25.3	5.3	5
Primary NW Primary *	8.0 to 10.2	9.3	0.7	9
Combined (sludge pumps)	4.0 to 11.6	8.3	1.3	25
Secondary (sludge pumps)	6.0 to 14.3	11.2	3.0	9
Contacted Sludges (CS-5 Samples)				
	Specific Resistance X 10^{11}	Average $\bar{x}$	σ	n
Primary - Grit Tank	36.0 to 12.5	60.8	31	9
Primary NW Primary *	33.6 to 70.0	52.4	11	9
Combined	22.0 to 12.6	62.8	24	25
Secondary	13.2 to 72.7	47.9	22	8
	B.F. % Cake Solids	$\bar{x}$	σ	n
Primary - Grit Tank	6.1-12.8	9.1	2.6	6
Primary NW Primary *	5.4-9.0	7.7	1.2	8
Combined (sludge pumps)	5.0-13.0	8.9	1.9	23
Secondary (sludge pumps)	2.1-22.1	13.4	7.0	11

* Sludge from primary clarifier, but with no waste activated sludge (see p7).

1. There is a significant difference in both specific resistance values and cake solids for primary sludge samples collected from the grit chamber and primary clarifier. Accordingly test results on these sludges were compared separately.

2. For all four sludges, the average specific resistance was higher for contacted sludges then for raw sludges, confirming the results for each set of runs previously shown, indicating that oxyozonation reduces dewaterability of the raw sludge.

3. The variability in specific resistance, as indicated by the standard deviation value (σ) was greater for the contacted sludge. This variability precluded interpretation of data to indicate minor or subtle effects of process parameters on the oxyozonation process.

4. Cake solids produced in the Buchner funnel test were higher before contacting for the raw primary sludge, from the grit chamber; however, for the other sludges, cake solids generally were similar before and after contacting.

Dewaterability with Polymer Addition and pH Adjustment

Presently the Monroe plant combined primary and secondary sludges are dewatered by vacuum filtration. The sludge is conditioned with polymer, 20 to 30 g/kg dry sludge solids, and a small amount of ferric chloride, 1 to 2 g/kg dry solids. Sludge samples from selected oxyozonation pilot plant test runs were conditioned, and specific resistivity was determined using the Buchner funnel test. The objective of these tests was to compare dewaterability of polymer conditioned raw sludge with polymer conditioned oxyozonated sludge, and to determine the effect, if any, of oxyozonation on polymer requirements. Since the oxyozonated sludge had been typically adjusted to a pH of 3 to 4, the effect of readjusting pH on polymer conditioned contacted sludge samples was also analyzed.

Figure 11 illustrates the effect of polymer dosage on specific resistance for the raw plant combined sludge, and for oxyozone contacted combined sludge samples. Raw sludge data from one run, number 27, conditioned with several polymer dosages are plotted. The polymer dose used to condition the raw sludge samples from the other tests was approximately that used at the Monroe plant for dewatering. The range of specific resistance for the 14 conditioned raw sludge samples tested was from 0.3 to 10.5 x 10^{11} cm/g as shown on the figure. Also shown are the results of tests on four samples of plant conditioned sludge collected at the vacuum filter. As can be observed, the plant dosage, while adequate for conditioning, was apparently not at the optimum dosage, which appeared to be in the range of 30 to 40 g/kg dry solids. The trade-off between an optimum dosage for dewatering rate and cake dryness and the cost of polymer, in addition to full scale performance, may explain the plant operation at the lower dosage. The results on the polymer conditioned contacted sludges, after pH was adjusted to the 6.0 to 7.0 range, were somewhat more variable than observed with the conditioned raw sludge, as can be seen on Figure 11. Optimum polymer dosage for the contacted sludge was also somewhat higher than for the raw sludges. A dosage of approximately 40 to 50 g/kg appeared to be optimum, although adequate dewatering probably could have been achieved using a dosage in the same range as used for the raw sludge.

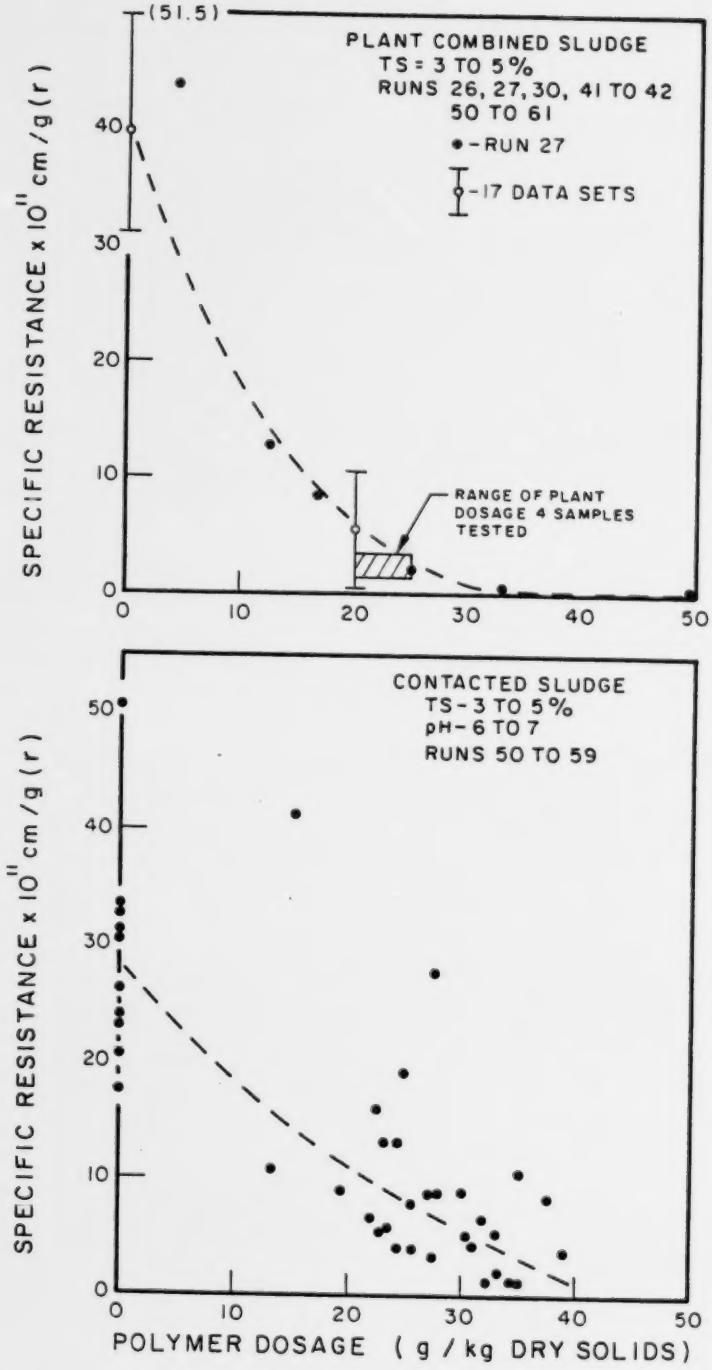


FIGURE 11. EFFECT OF POLYMER DOSAGE ON SPECIFIC RESISTANCE FOR RAW AND CONTACTED COMBINED SLUDGE

Figure 12 illustrates the average and range of specific resistance values for combined sludges tested in runs 50 to 59, prior to and with polymer conditioning. A number of observations can be made from these results.

1. Polymer conditioning, necessary for dewatering the sludge, effected approximately a tenfold reduction in specific resistance.

2. Acidifiction of the raw combined sludge to pH 3 to 4 decreased specific resistance.

3. Similar to previous results, oxyozonation contact increased sludge specific resistance.

4. Polymer requirements for contacted sludges to achieve similar specific resistance values were about 40 to 60 percent greater than required for raw sludge samples.

Table 5 presents data from several runs comparing specific resistance of contacted sludges with and without pH adjustment and with and without polymer conditioning. Both pH adjustment to the 6 to 7 range and polymer conditioning decreased the specific reistance values.

TABLE 5. COMPARISON OF DEWATERABILITY OF OXYOZO CONTACTED SLUDGES WITH AND WITHOUT POLYMER ADDITION AND pH ADJUSTMENT

Without Polymers

Run Number	Type Sludge	pH 3 to 4		pH 6 to 7	
		r	(% TS)	r	(% TS)
38	P	49.8	9.0	24.4	15.7
39	P	54.8	8.0	31.6	17.5
40	PC	71.3	8.8	46.6	9.6
41	PC	57.7	8.3	32.5	14.0
42	PC	56.7	8.1	35.5	16.1

With Polymers

Run Number	pH 3 to 4			pH 6 to 7		
	Polymer Dose (m/kg)	r	(% TS)	Polymer Dose (g/kg)	r	(% TS)
38	24.2	16.5	22.7	-	-	-
39	27.7	18.0	19.3	24.5	11.3	22.8
40	28.1	35.8	15.7	28.3	5.4	21.4
41	27.2	23.5	18.5	25.9	6.2	20.5
42	28.0	23.5	20.0	25.6	11.3	20.9

r - specific resistance cm/g x 10^{11}
P - primary sludge
PC - plant combined sludge

Table 6 summarizes the pilot plant data on polymer conditioning of the sludges tested. Most of the data on conditioning was with the combined sludges, after readjustment of pH to the 6 to 7 range. As can be observed, the polymer conditioned raw sludge specific resistance (at a lower polymer dosage) averaged approximately half that of the contacted sludge. The cake solids for the contacted sludge was somewhat higher than for the raw sludges tested.

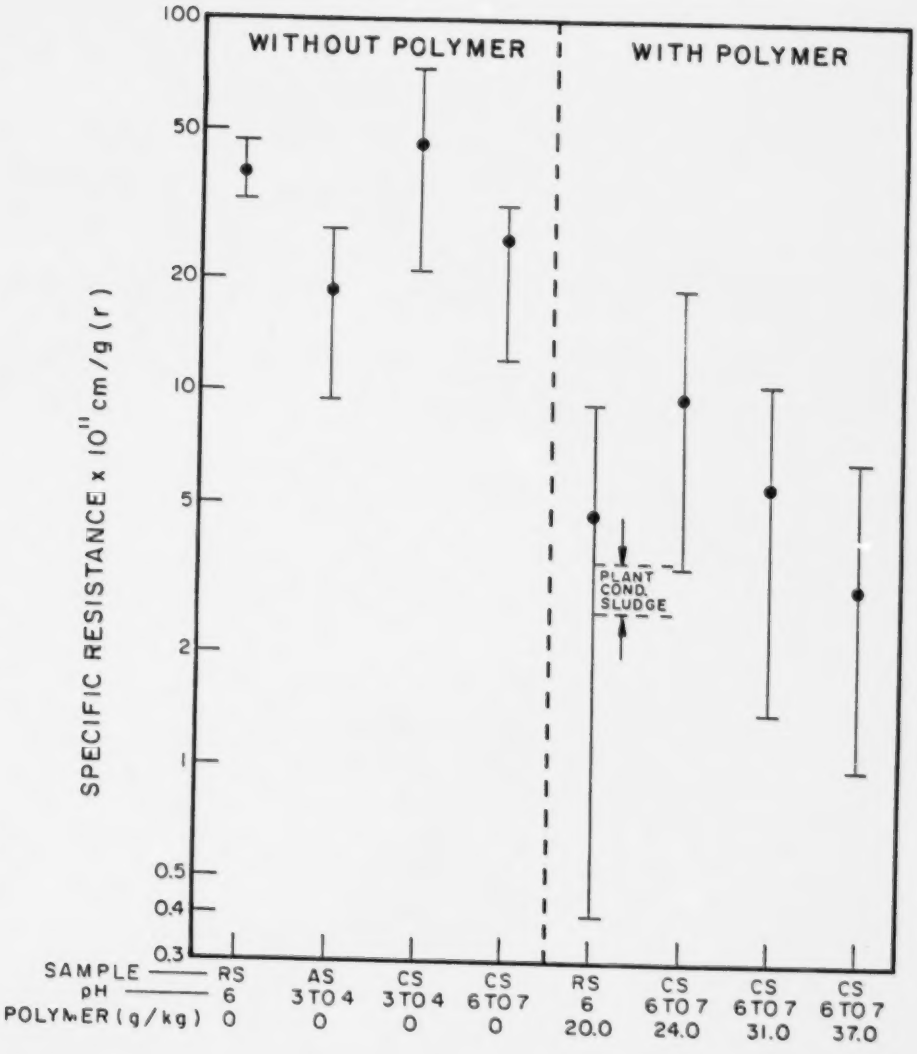


FIGURE 12. COMPARISON OF SLUDGE SPECIFIC RESISTANCE WITH AND WITHOUT POLYMER CONDITIONING

TABLE 6. SUMMARY OF POLYMER CONDITIONING, BUCHNER FUNNEL RESULTS

Raw Sludges

	Specific Resistance X 10^{11}	Average $\bar{x}$	σ	n	Average Polymer Dose kg/kg
Primary	0.9 - 35.5	8.9	-	3	24
Primary	1.04 - 2.2	1.3	-	3	15
Combined	0.3 - 10.5	4.2	3.4	24	23
	B.F. % Cake Solids	$\bar{x}$	σ	n	Dose
Primary	9.7 - 17.8	14.9	-	3	24
Secondary	13.2 - 15.3	14.1	-	3	15
Combined	6.5 - 19.2	15.1	2.6	21	23

Contacted Sludges

	Specific Resistance X 10^{11}	Average $\bar{x}$	σ	n	Average Polymer Dose kg/kg
Primary	11.3 - 36.4	22.1	-	4	24
Primary	6.1 - 10.4	10.3	-	3	15
Combined (pH 6-7)	1.7 - 19.1	6.1	4.2	26	29
	B.F. % Cake Solids	$\bar{x}$	σ	n	Dose
Primary	7.6 - 22.8	17.7	-	3	24
Secondary	13.9 - 19.2	16.3	-	3	15
Combined (pH 6-7)	14.1 - 22.9	18.6	2.5	26	29

Sludge Stabilization

Although the focus of this project was on the dewaterability of the oxyozonated sludges, the process has also been proposed for sludge stabilization. A previous study[4] was discussed in Section 1. In this previous study, the process was operated under one set of conditions, namely at a 100 percent ozone setting, and pH 3 to 4. The results indicated the process effectively reduced coliform concentrations in the sludge. In this current study, selected samples of contacted sludge were analyzed for fecal coliform concentrations. In addition, COD was run on total and filtered samples of raw and contacted sludge to determine the effect, if any, of the process on reduction of total COD and/or solubili-

zation of COD. Total solids and total volatile solids analyses were also conducted on raw and contacted sludges.

Table 7 presents the results of fecal coliform analyses of sludge samples from 13 runs. The results show that a substantial reduction of the fecal coliform count is realized by acidification of the sludge.

TABLE 7. FECAL COLIFORM DATA[a]

Run Number	Raw Sludge	pH[b]	Acidified Sludge	Contacted Sludge (time/minutes) 30	60	90	120	150
38	3.0×10^{7}	3.5	$<10^{8}$	-	$<10^{7}$	-	$<10^{7}$	-
39	1.6×10^{7}	3.5	2.0×10^{7}	-	$<10^{7}$	-	$<10^{7}$	-
40	5.9×10^{7}	3.5	$<10^{7}$	-	$<10^{7}$	-	$<10^{7}$	-
41	6.3×10^{8}	3.5	$<10^{7}$	-	$<10^{7}$	-	$<10^{7}$	-
42	1.6×10^{7}	3.5	$<10^{7}$	-	1.0×10^{7}	-	$<10^{7}$	-
43	1.6×10^{8}	3.5	3.4×10^{7}	-	$<10^{7}$	-	$<10^{7}$	-
50	2.6×10^{8}	3.5	$<10^{8}$	-	$<10^{8}$	-	-	-
51	8.6×10^{9}	3.5	3.5×10^{8}	-	-	-	$<10^{8}$	-
57	2.0×10^{9}	3.3	$<10^{8}$	-	-	-	$<10^{8}$	-
58	3.4×10^{8}	3.5	$<10^{8}$	-	$<10^{8}$	-	-	-
59	6.3×10^{9}	3.3	1×10^{7}	-	-	-	$<10^{8}$	-
60	2.0×10^{7}	3.5	$<10^{7}$	$<10^{7}$	$<10^{7}$	$<10^{8}$	$<10^{7}$	$<10^{7}$
61	5.7×10^{7}	3.7	1×10^{7}	$<10^{7}$	-	2.0×10^{8}	-	$<10^{7}$

[a] All fecal coliform data reported as count per 100 mls (MPN/100 ml)
[b] pH after addition of acid

After 60 minutes of oxyozonation, all samples analyzed, except for one anomalous result, showed essentially no remaining fecal coliforms. The WSCC study[4] showed that for thickened waste sludge, fecal coliform reduction from 1.4×10^{8} to 1.8×10^{4} MPN/100 ml was achieved by acidification, and after about 60 to 120 minutes of ozonation, fecal coliforms results averaged less than 1×10^{3} MPN/100 ml. Process optimization tests to determine the effect of varying pH levels, ozone dosage and contact time (0 to 60 minutes) were not included within the scope of the study; however, it would appear from these results that further work in this area would be required to determine the optimum pH level and ozone contact time for disinfection.

Figure 13 illustrates the effect of oxyozonation on total and filtered (soluble) COD of the three sludges tested. The data plotted compares raw sludge with contacted sludge, after oxyozonation (150 minutes at 412 kPa (60 psi) in most tests), and compares the raw sludge filtrate COD with the contacted sludge filtrate. The curve through each figure was drawn from the origin through the average of the data. The data showed much scatter, and essentially no reduction in total COD for the sludges could be demonstrated; however, an increase in filtrate COD after oxyozonation was

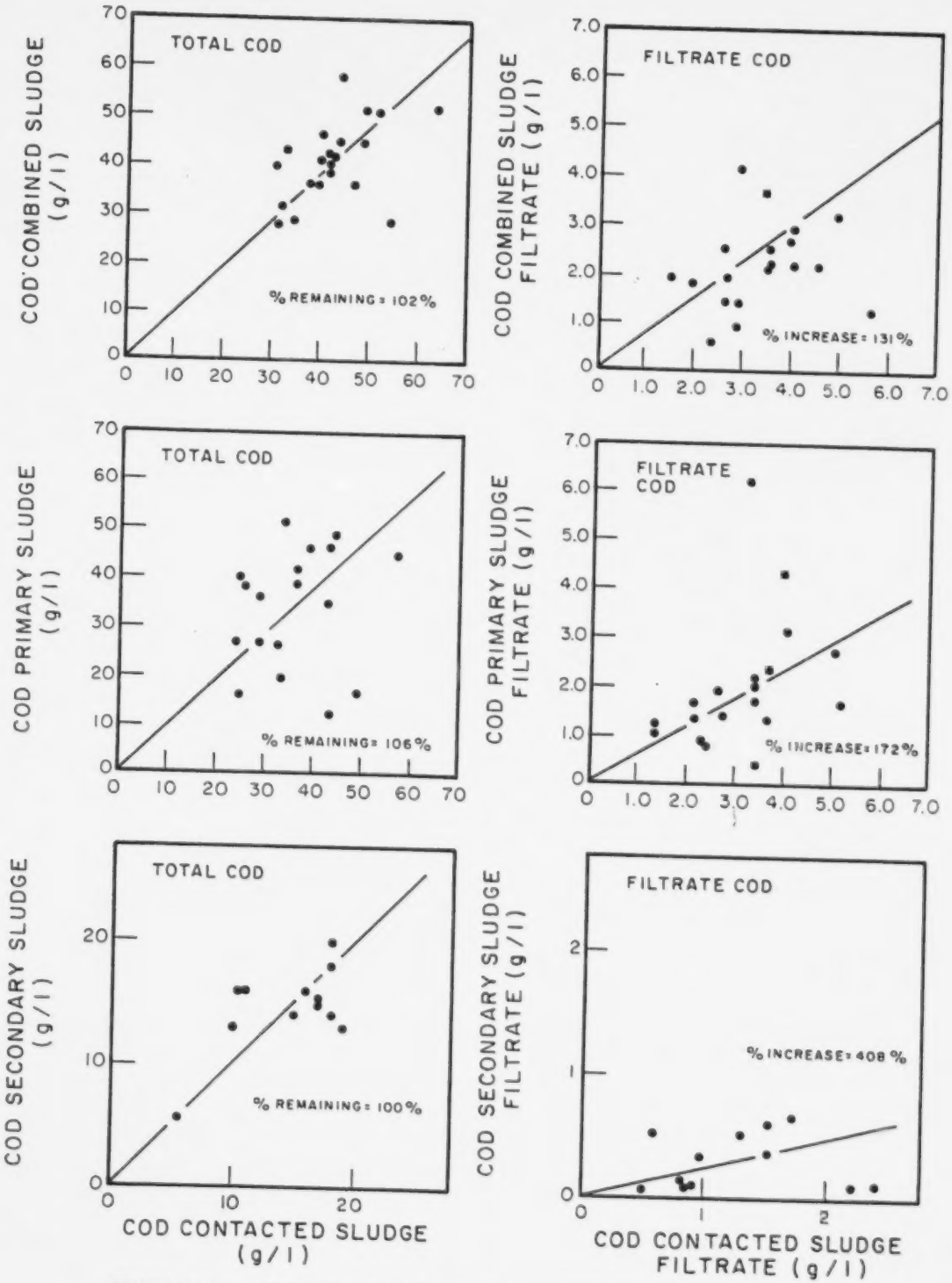


FIGURE 13. COMPARISON OF TOTAL AND FILTRATE COD ON RAW AND CONTACTED COMBINED SLUDGE

found, particularly for the secondary sludge. In incorporating the process into a sludge handling system, the filtrate from dewatering typically would be returned to the plant influent. A recycle of filtrate COD load would require evaluation with respect to its effect on plant design and performance.

Table 8 compares total and volatile solids of the raw and contacted sludges. The range of values for each, as well as the average value, standard deviation and number of observations are shown in the table. Although the data indicate a slight increase in total solids from raw to contacted sludge, the differences are all within a range which is not statistically significant. The volatile fraction of the sludge solids shows differences between raw and contacted sludges which are within the accuracy of the test data and therefore not significant.

TABLE 8. SUMMARY OF TOTAL SOLIDS DATA ON SLUDGES SAMPLED

	Total Solids (%)				% Volatile Total Solids			
	Range	$\bar{x}$	s	n	Range	$\bar{x}$	s	n
Raw Sludge								
Primary (Grit)	1.6 to 6.7	3.64	1.6	10	51.6 to 66.7	59.4	5.4	10
Primary (NW)	3.9 to 5.4	4.65	0.5	9	55.0 to 60.7	58.4	2.2	9
Plant Combined	2.9 to 5.2	4.40	0.5	25	46.1 to 67.7	56.3	5.1	27
Secondary	0.6 to 2.1	1.60	0.4	14	42.9 to 75.3	58.6	10.1	12
Contacted Sludge								
Primary (Grit)	1.9 to 6.4	3.8	1.7	8	57.0 to 66.7	64.5	3.5	8
Primary (NW)	3.9 to 5.3	5.1	0.8	8	53.0 to 61.7	58.3	3.3	9
Plant Combined	3.5 to 5.5	4.7	0.5	23	47.2 to 63.4	55.9	5.4	17
Secondary	0.7 to 2.3	1.6	0.6	13	40.7 to 73.5	58.2	9.3	11

Table 9 summarizes pilot plant total and volatile solids reduction data from the test runs. The values indicate a slight increase in total solids and a decrease in volatile solids. Within the accuracy of test data,

TABLE 9. SUMMARY OF DATA PERCENT REDUCTION OF TOTAL SOLIDS AND TOTAL VOLATILE SOLIDS BY OXYOZOSYNTHESIS PILOT RUNS

	Total Solids Reduction (%)				Total Volatile Solids Reduction			
	Range	$\bar{x}$	s	n	95% Confidence Range	$\bar{x}$	s	n
Primary (Grit)	-18.8 to 23.8	-2.1	13.9	9	-18.3 to 5.1	-9.3	6.1	8
Primary (NW)	-26.7 to 8.2	-5.4	11.6	9	-2.2 to 5.0	0.2	2.4	9
Plant Combined	-52.5 to 18.8	-2.8	15.3	18	-5.6 to 19.7	2.6	7.6	16
Secondary	-35.1 to 35.3	0.3	28.0	12	-17.9 to 12.5	1.0	9.1	10

however, on the average, these results do not indicate a significant reduction in either total or volatile solids by oxyozonation. Of interest, however, is the range in results (similar to the scatter seen in the COD test results) observed, and the potential for misinterpretation of results based on one or two tests.

Table 10 presents the analyses of filtrate samples from raw and contacted sludges.

TABLE 10. AVERAGED DATA OF ANALYSES OF SLUDGE SAMPLE FILTRATES

A. BOD and Nutrients

Sludge	N	BOD_5		TKN		NH_3-N		PO_4-P	
		Raw	Contact	Raw	Contact	Raw	Contact	Raw	Contact
Primary	3	2440	1470	75	124	380	273	4.6	59
Secondary	2	550	590	36	90	-	-	2.3	25
Plant Combined	7	2760	1920	155	155	125	93	6.6	14

B. Heavy Metals

Sludge	N	Fe			Zn			Cr			Pb			Cu		
		Raw	Acid	Contact	Raw	Acid	Contact	Raw	Acid	Contact	Raw	Acid	Contact	Raw	Acid	Contact
Primary	2	6.2	285	82	0.4	4.9	22	<0.2	0.3	0.6	-	-	-	-	-	-
Secondary	2	1.4	67	9.0	0.02	10.0	17	<0.2	<0.2	<0.2	-	-	-	-	-	-
Plant Combined	6	17	148	101	<0.2	0.4	27	<0.2	<0.2	<0.2	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1

Units - mg/l
N - Number of samples analyzed.

Most of the data are for the combined plant sludge. A reduction in the BOD_5 of the filtrate after oxyozonation, was observed, in contrast to the COD results which indicated an increase.

No conclusions on TKN or NH_3-N can be drawn from this limited data, except that possibly no significant reductions or increases in either would be expected. Phosphorus in the filtrate, however, appeared to have increased, due to solubilization in the acidification step. Iron and zinc were solubilized by acidification as indicated by the increase in concentration in filtrate samples after acidification. Subsequently, ozonation appeared to reduce the soluble iron content. Chrome, lead, and copper were not found in significant concentrations in the filtrates from raw or contacted sludges.

Process Consumables

Use of power and chemicals associated with the hyperbaric oxyozosynthesis process were determined based on the pilot plant studies. These values could not be optimized, since the process had, essentially, no significant beneficial effect on sludge dewaterability. The consumables were, therefore, based on using a pilot plant operating mode suggested by the results of these tests and the manufacturer's recommendations.

Acid and Base Requirements. The oxyozonation process was developed to treat sludges at reduced pH levels to enhance the effectiveness of the ozone. The pilot plant tests did not clearly indicate an optimum pH with respect to dewaterability. A pH in the range of 3 to 4, however, was generally recommended or used by the process manufacturer and others[1,3,4,6] for oxyozonation.

The pH titration curves were run on sludge samples to determine acid requirements. Several typical results are shown on Figure 14. The pH decreased fairly constantly as dosage was increased, to an approximate pH of 3.0. Thereafter, the acid dosage requirements increased significantly to affect further reductions in pH. Very little pH reduction was observed at levels below 2 for large increases in acid. Acid requirements based on the pH titration curve were 1.8 to 2.4 kg of concentrated sulfuric acid, per cubic meter of secondary sludge and 3 to 4 kg of acid per cubic meter of primary and combined sludges, to reduce pH to 3 to 4.

During the titration tests it was noted that pH, after each acid addition, would gradually increase, as a slow reaction with sludge constitutents apparently neutralized the acid. As a result, it was found in acidifying the sludge samples for the pilot plant runs, that somewhat more acid than was determined in the titration test was necessary to ensure achieving a desired pH level throughout the two to three hour contact period. Acid utilization and final pH for each run is listed in Table A-1 in the Appendix. This data was analyzed to determine acid requirements for the plant combined sludge to achieve a pH between 3.0 and 4.0. The acid requirement, using 97 percent sulfuric acid, averaged 5.3 kg per cubic meter of sludge and ranged from 4.1 to 5.5 kg per cubic meter.

Acid requirements based on solids concentrations were determined for the sludges tested, and the comparison is shown on Figure 15. The mean acid requirement was about 0.12 g of sulfuric acid per g of sludge solids. This figure compares closely with the 0.15 g/g dry solids found in the WSSC study.[4] Based on the average Monroe plant combined sludge concentration of 3.4 percent, the average acid required to depress pH to the 3 to 4 range would be 4.1 kg per cubic meter of sludge, somewhat lower than the average quantity actually used for the sludges tested in the pilot plant program.

Neutralization of the contacted sludge to a pH range of six to seven prior to dewatering reduced the polymer dose required as indicated in the previous section. This observation was also made in the WSSC study.[4] Pilot plant data showed an average caustic requirement of 4.6 kg of sodium hydroxide (50 percent NaOH 1.55 sp.gr.) per cubic meter of sludge, with a range of 1.7 to 5.6 kg/cubic meter required.

Oxygen and Ozone Requirements. The initial pilot test run data showed that ozone did not appear to have any significant effect on sludge dewaterability. These results preclude optimization of ozone dosages for dewaterability. The use of oxygen and ozone, however, is an integral component of the hyperbaric oxyozosynthesis process. According to the manufacturer and developer[1,2] oxygen and ozone provide stabilization through disinfection and odor reduction, in addition to direct oxidation or synthesis of contaminants in the sludge.

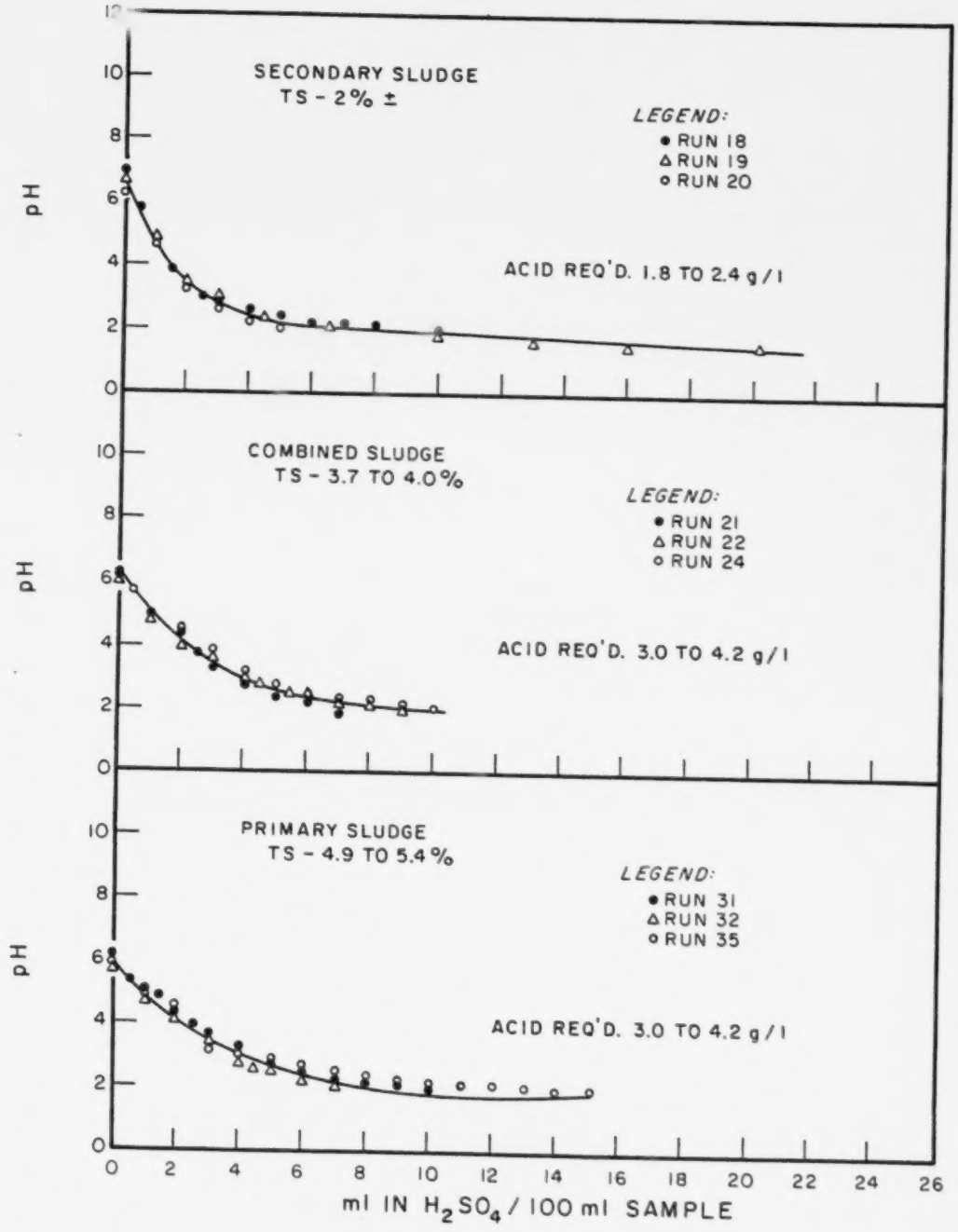


FIGURE 14. pH TITRATION CURVES FOR SLUDGES TESTED

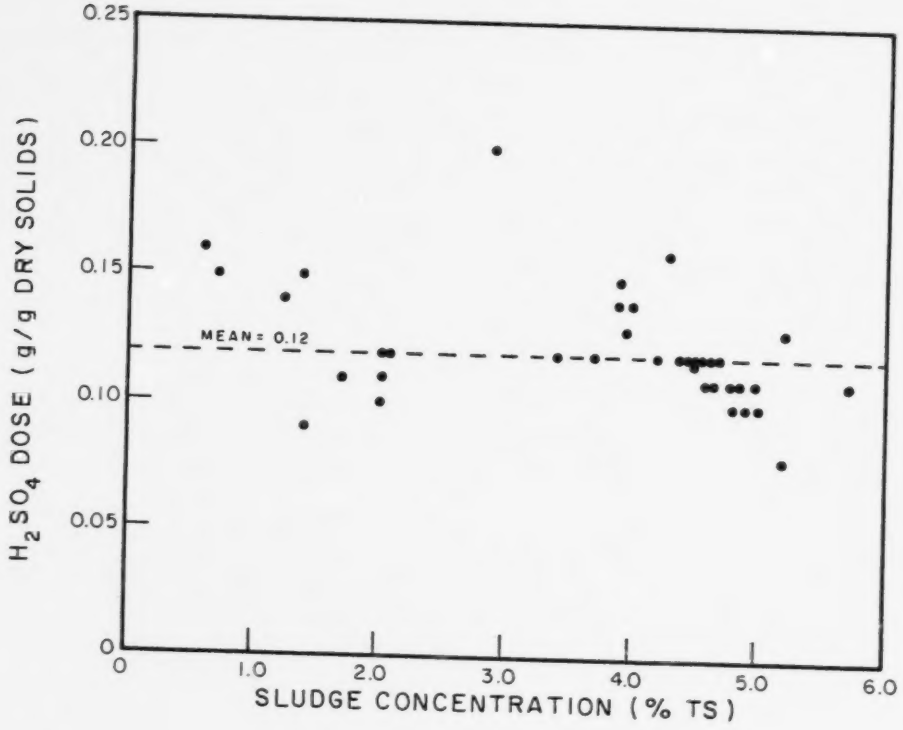


FIGURE 15. ACID REQUIRED TO ADJUST SLUDGE pH TO 3 TO 4 BASED ON SOLIDS CONCENTRATION

The pilot plant was supplied with an ozonator described previously, which, based on measured ozone output, produced about 0.7 kg of ozone/day at an average oxygen gas flow of 0.95 m^3/hr, and 2.3 percent ozone concentration at a 100 percent setting on the ozone output meter. The equipment rated capacity was 1.2 kg of ozone per day at three percent concentration and a gas flow of about 1.22 m^3/hr would be required. At 0.95 m^3/hr and 100 percent output the gas concentration, based on the manufacturer's rated output curve for the model should have been about 3.5 percent with an output of about 1.1 kg of ozone per day. Apparently, the efficiency of the ozonator, which had been in use with the pilot plant for several years, had decreased from its rated capacity.

Oxygen consumption can occur in two phases of the operation, rapid pressurization and ozonation, as previously described. Rapid pressurization occurs at the start of the run, when, after filling the reactor to half volume with sludge, oxygen is added to a specified pressure, before ozonation is started. This step was achieved in a matter of minutes directly from the oxygen supply during the pilot plant studies. The ozonation step of the process supplies both oxygen and ozone to the reactor. In this step, oxygen was applied to the pilot plant reactor at an average rate of 3.2 kg per cubic meter of sludge per hour or 2.39 standard cubic meters per cubic meter of sludge per hour.

Table 11 summarizes the oxygen and ozone use for three modes of operation. Mode 1 is IWWRT's suggested operational procedure. This procedure differs from the other two in the use of the rapid pressurization step. As a result, modes 2 and 3 are for 60 and 90 minute contact and mixing with ozone. This step was not used in runs 38 to 59 (see Table A-1 in the Appendix). A significant amount of oxygen is used in this step, however, pilot studies showed coliform reduction could be achieved without this step. The final pressures were, 207 and 412 kPa, respectively (30 and 60 psig). Coliform reduction to <10 MPN/100 ml was achieved at both detention times.

TABLE 11. PILOT PLANT OXYGEN AND OZONE UTILIZATION

	Rapid Pressurization			Oxyozonation				
Mode	Initial Pressure (Pax10^5)	Adjust Pressure (Pax10^5)	Oxygen Consumed (m^3)	Final Pressure (Pax10^5)	Ozonation Time (min)	Ozone Generated (kg)	Oxygen Consumed (m^3)	Total O_2 Consumed (m^3)
1	1.24	2.78	0.5	4.14	60	0.028	0.91	1.42
2	0	0	0	2.07	60	0.028	0.91	0.91
3	0	0	0	4.14	90	0.042	1.36	1.36

Pa - Pascal (1.45×10^{-4} psi)

As can be observed, oxygen consumption will depend upon the operational mode selected and the length of time ozone is produced and charged into the reactor. Operational mode 2 for sludge stabilization was found adequate in this study. The oxygen requirement was about 2.4 standard cubic meters per cubic meter of sludge contacted.

It should be clearly recognized that this study did not optimize oxygen-ozonation requirements for sludge stabilization. The use of oxygen and ozone in the studies, except for the tests run to determine the effect of ozone dosage on dewaterability, were run at the limits of the equipment supplied with the pilot plant. Since, as measured by fecal coliform reduction and odor reduction, the operating gas modes used were adequate, it may be assumed that possibly somewhat lower dosages may also have been adequate. This aspect of the process involving optimization of oxygen and ozone use with respect to sludge stabilization is an area requiring further research.

Power Requirements. The oxyozonation process has several power requirements for the various pieces of equipment used. The manufacturer is apparently adjusting and refining the specifics of the equipment for full scale installations; however, based on these pilot plant studies, a preliminary power usage was developed and is shown in Table 12.

TABLE 12. POWER REQUIREMENTS FOR OXYOZOSYNTHESIS PILOT PLANT REACTOR OPERATING SLUDGE VOLUME 0.38 M^3

Equipment	KW	Operating Time (minutes)	Total Power (KWH)
Recycle Pump	1.1	60 to 95	1.2 to 1.7
Compressor (air sludge pump)	0.6	10	0.1
Mixer	0.4	65 to 95	0.43 to 0.63
Comminutor	0.2	65 to 95	0.22 to 0.32
Gas Pump	0.2	65 to 95	0.20 to 0.30
O_3 Generator (PCI-GI)	0.2	60 to 90	0.20 to 0.30
Total			2.35 to 3.35

The major power consumer is the recycle pump, followed by the mixer comminuter, gas pumps and ozone generator. Total power required for 60 minutes ozonation contact time is in the range of 6.2 kwh/m^3 sludge contacted. The WSSC[4] study at two hours contact time reported a power usage of 12.6 kwh/m^3 of sludge.

Summary of Consumables Used for Hyperbaric Oxyozonation. Based upon the pilot plant data, the utilization of consumables for oxyozonation of the Monroe Plant combined sludge at three to five percent total solids is summarized in the following Table 13. Usage based on sludge volume and on dry solids basis are both shown.

TABLE 13. AVERAGE CONSUMABLES FOR OXYOZONATION OF COMBINED PLANT SLUDGE (3.5 PERCENT TS)

Sulfuric Acid (97% @ 1.83 sp.gr)	5.3 kg/m^3 of sludge	0.15 kg/kg dry solids
Oxygen (15°C, 1 Atm)	2.7 to 3.7 m^3/m^3 of sludge	3.2 to 4.8 kg/m^3
Caustic (50% @ 1.55 sp.gr)	4.6 kg/m^3 of sludge	0.13 kg/kg dry solids
Polymer (Secodyne 750)	1 to 1.5 kg/m^3 of sludge	30 to 40 g/kg dry solids
Power Estimated	6 to 9 kwh/m^3 of sludge	60 to 90 minutes contact time

SECTION 5

SYSTEM COST ANALYSIS

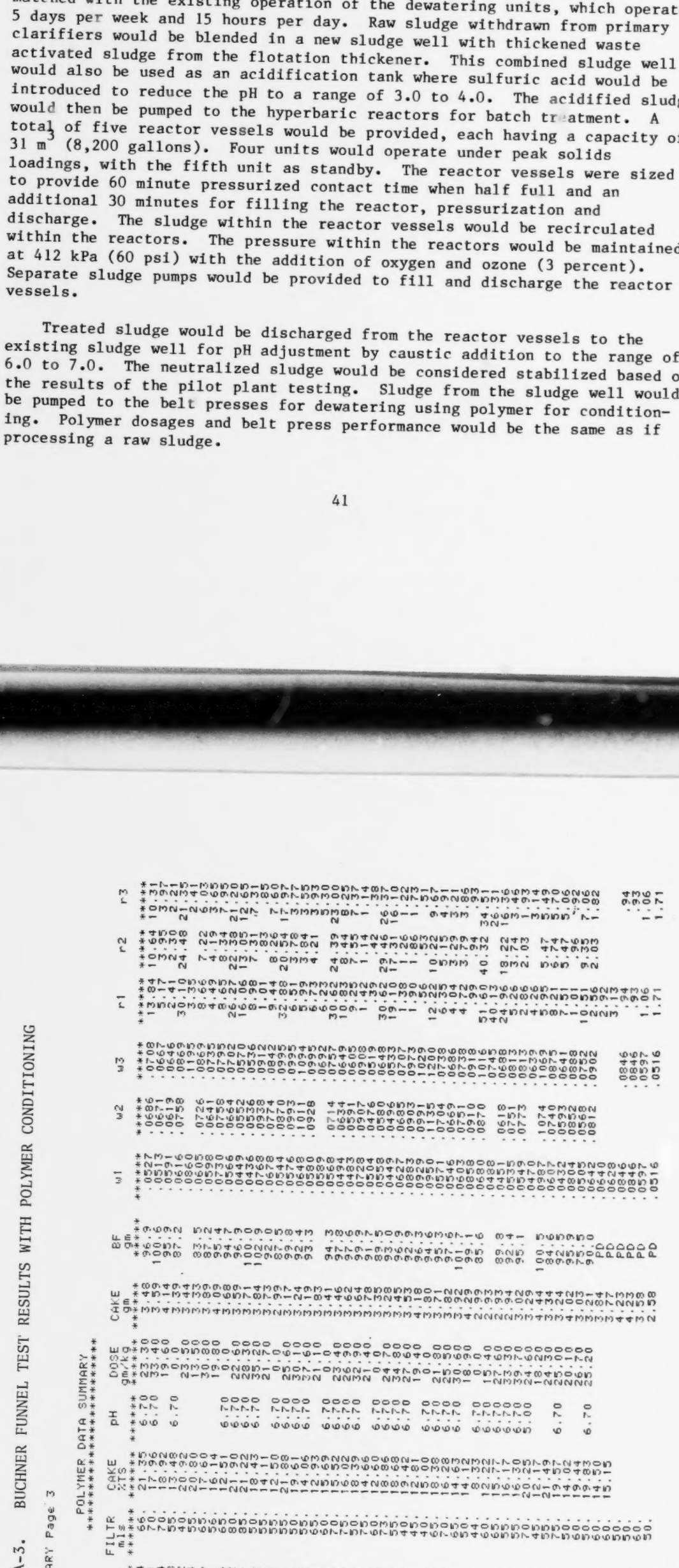
Design Criteria

The results of the pilot plant investigations were used to develop the design criteria for a full scale hyperbaric oxyozosynthesis process scheme for the Monroe Metropolitan Area Wastewater Treatment Facility. The capital and operating costs associated with the process were then estimated in order to determine the unit costs for hyperbaric oxyozosynthesis sludge stabilization.

The sludge treatment process scheme and solids loadings are shown on Figure 16. The process scheme was designed to meet the peak week solids production of 18,675 kg per day (41,165 pounds/day), at 3 percent solids concentration. Operation of the hyperbaric oxyozosynthesis process was matched with the existing operation of the dewatering units, which operate 5 days per week and 15 hours per day. Raw sludge withdrawn from primary clarifiers would be blended in a new sludge well with thickened waste activated sludge from the flotation thickener. This combined sludge well would also be used as an acidification tank where sulfuric acid would be introduced to reduce the pH to a range of 3.0 to 4.0. The acidified sludge would then be pumped to the hyperbaric reactors for batch treatment. A total of five reactor vessels would be provided, each having a capacity of 31 m^3 (8,200 gallons). Four units would operate under peak solids loadings, with the fifth unit as standby. The reactor vessels were sized to provide 60 minute pressurized contact time when half full and an additional 30 minutes for filling the reactor, pressurization and discharge. The sludge within the reactor vessels would be recirculated within the reactors. The pressure within the reactors would be maintained at 412 kPa (60 psi) with the addition of oxygen and ozone (3 percent). Separate sludge pumps would be provided to fill and discharge the reactor vessels.

Treated sludge would be discharged from the reactor vessels to the existing sludge well for pH adjustment by caustic addition to the range of 6.0 to 7.0. The neutralized sludge would be considered stabilized based on the results of the pilot plant testing. Sludge from the sludge well would be pumped to the belt presses for dewatering using polymer for conditioning. Polymer dosages and belt press performance would be the same as if processing a raw sludge.

TABLE A-3. BUCHNER FUNNEL TEST RESULTS WITH POLYMER CONDITIONING



POLYMER DATA SUMMARY

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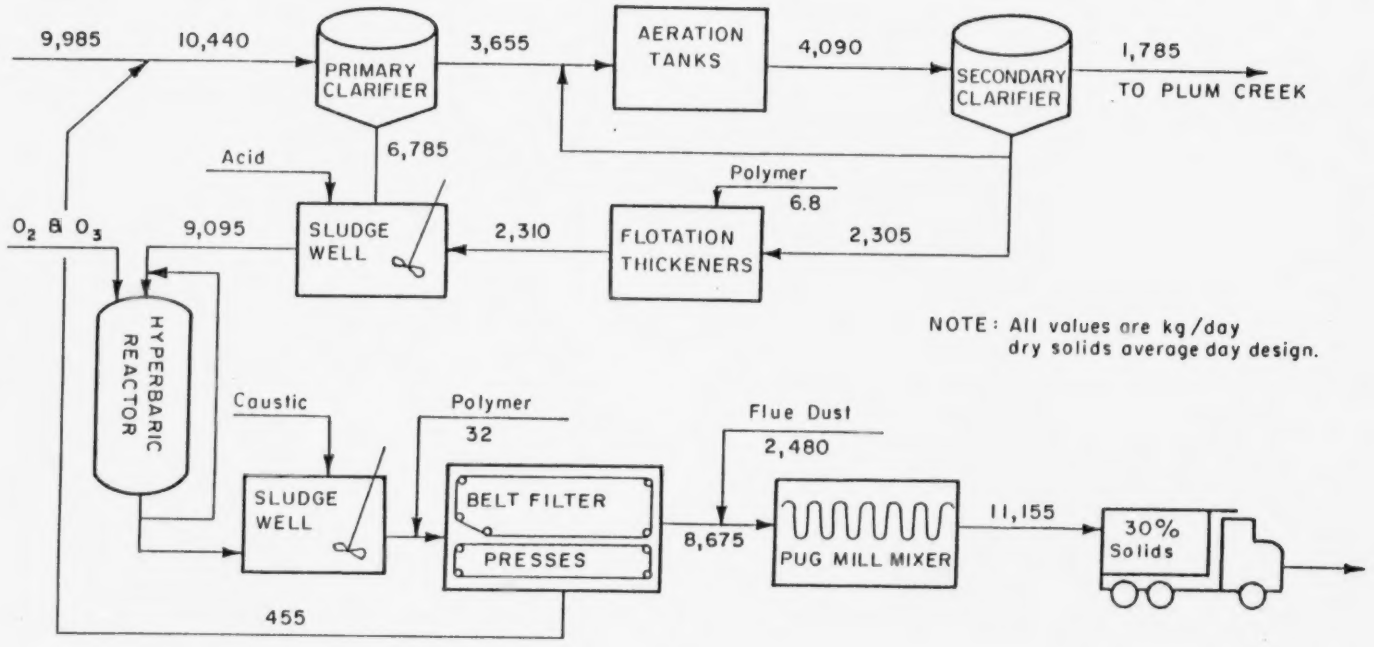

FIGURE 16. HYPERBARIC OXYOZOSYNTHESIS PROCESS SCHEME

The hyperbaric oxyozosynthetis system design parameters and components are presented in Table 14. The process scheme would include five individual units, each consisting of a plunger type sludge pump, reactor vessel with appurtenances, an ozone generator and a compressor to pressurize the oxygen-ozone mixture within the reactor. Oxygen would be delivered to the plant site in pressurized tank trucks. All components of the hyperbaric process would be enclosed in a 6464 square meter (5,000 square foot) pre-engineered metal building.

TABLE 14. HYPERBARIC OXYOZOSYNTHESIS SYSTEM DESIGN CRITERIA
(Peak Week)

Sludge Flow m^3/day (gallons/day)	622 (164,484)
Sludge Solids Concentration, percent	3
Number of Batch Operations per day	40
Number of Reactor Vessels	5
Reactor Capacity, cubic meters (gallons)	31 (8,200)
Number of Ozone Generators	5
Ozone Generator Maximum Capacity, kg/day (lbs/day)	33 (73)
Number of Sludge Recirculation and Transfer Pumps	5
Number of Sludge Blending Tanks	1
Number of Sludge Blending Tank Mixers	2
Number of Reactor Mixers	5
Number of Acid Storage Tanks	1
Acid Storage Tank Capacity, cubic meters (gallons)	75 (20,000)
Chemical Pumps	2
Number of Compressors	5
Number of Caustic Day Tanks	2
Number of Day Tank Mixers	2
Number of Caustic Solution Pumps	2

Estimated Costs

A present worth analysis of the hyperbaric oxyozosynthesis process scheme was performed to determine the estimated cost per ton for sludge stabilization. A 7-5/8 percent discount rate was used over a 20 year life cycle. Salvage values for the process equipment and building were assumed to be zero at the end of 20 years. Table 15 is a summary of the present worth analysis. The estimated present worth for sludge stabilization using the hyperbaric oxyozosynthesis process is $230 per metric ton dry solids.

TABLE 15. HYPERBARIC OXYOZOSYNTHESIS SYSTEM COST ANALYSIS

Annual Capital Cost	$196,293
Subtotal	$196,293
Annual O & M	
Labor - 2-1/2 Operator and 1/2 Maintenance at $17/hr.	106,080
Parts and Repairs - 7 percent Equipment Costs	35,000
Electricity - 7.5 kwh/m^3 at $.06/kwh	35,470
Oxygen - 851 cubic meters (30, 050 cu. ft/day) at $.22/cubic meter ($.61/100 cu. ft)	48,680
Acid - 1364 kg/day (3,008 lbs/day) at $0.11/kg ($.05/lb)	39,010
Caustic - 1182 kg/day (2,607 lbs/day) at $0.27/kg ($.12 lb/day)	82,980
Subtotal	$347,220
Total Annual Cost	$543,513
Average Annual Dry Solids Production metric ton/year (ton/year)	2,365 (2,607)
Unit Cost at $/metric ton ($/ton)	$229.81 (208.48)

Note: Daily costs multiplied by 260 operating days per year.

REFERENCES

[1]International Wastewater Reclamation Technologies, Inc., Fact Sheet Oxyozonation-Treatment of Wastewater or Sludge for Ultimate Disposal, July 1981.

[2]Newkumet, C., "Treating Sludge by Oxyozosynthesis: Waiting for a Miracle to Happen," Sludge Magazine, Volume 3, Number 4, July, August 1980.

[3]Peterson, S.A., Oxyozosynthesis Sludge Treatment Process, A Case Study of International Wastewater Reclamation Technologies, Inc., New Process, Presented at ASCE Innovative and Alternate Workshop on Wastewater Technology, University of Florida, Gainesville, Florida, June 1982.

[4]Jones, E.R., "Oxyozonation of Waste Activated Sludge at the Western Branch STP," Washington Suburban Sanitary Commission Report, July 1983.

[5]Peterson, S.A., "Oxyozosynthesis: An Innovative Sludge Treatment Process," Proceedings from New Jersey Water Pollution Control Association Annual Meeting, May 1983.

[6]IWWRT, Oxyosynthesis Field Testing Report for Monroe, Michigan, April 1983.

APPENDIX

A-1. Pilot Plant Data Summary

A-2. Buchner Funnel Test Data

A-3. Buchner Funnel Test Results with Polymer Conditioning

A-4. Quality Assurance Data
- a. Buchner Funnel Replicate Tests
- b. Solids Analyses Replicate Tests
- c. Duplicate Pilot Plant Runs

A-5. Canton Analytical Laboratory Sample Analyses
- a. COD
- b. BOD, Nutrients and Heavy Metals
- c. Quality Assurance Quality Control Results

A-6. Pilot Plant Ozonator Calibration
Monitor Versus KI Test
% Output Versus Ozone Concentration

A-7. Buchner Funnel Apparatus/Test Description

A-8. Pilot Plant Data Sheet

A-9. Review Comments from Ozonics Corporation

TABLE A-1. PILOT PLANT DATA SUMMARY

HYPERBARIC OXYOSYNTHESIS PILOT PLANT DATA SUMMARY

RUN DATA				ACID CONSUMED			OZONATION							
RUN NO	SLUDGE VOL l	TYPE	TS %	INIT pH	VOL l	ADJ pH	INIT psi	O2 cf	ADJ psi	O3 FEED %	O2 USED cf	FIN psi	TIME min	O3 lbs	TTL O2 cf	TEMP C
1	351.	p	2.73	6.9	.000	6.9	17.	20.	40.	2.30	95.	60.	185.	.187	115.	12.
2	351.	p	2.49		.570	4.0	15.	27.	41.	2.30	90.	60.	182.	.177	117.	12.
3	367.	p	2.27		.750	2.3	20.	18.	40.	2.30	116.	60.	182.	.228	134.	13.
4	367.	p	1.62		.193	4.9	16.	21.	40.	2.30	92.	60.	179.	.181	113.	11.
5	367.	p	3.70	1	.497	2.1	18.	20.	40.	2.30	97.	60.	185.	.191	117.	13.
6	378.	s	.76	6.7	.000	6.7	19.	21.	40.	2.30	106.	60.	181.	.208	127.	11.
7	367.	s	.70		.220	3.1	11.	23.	41.	2.30	118.	60.	182.	.232	141.	12.
8	349.	s	1.30		.379	3.1	18.	21.	43.	2.30	108.	60.	192.	.212	129.	13.
9	356.	s	1.36	1	.133	1.8	18.	20.	40.	2.30	105.	60.	177.	.206	125.	14.
10	360.	s	1.67		.177	4.8	16.	19.	40.	2.30	113.	60.	178.	.222	132.	14.
11	377.	p	4.23	1	.050	2.8	19.	18.	40.	1.40	112.	60.	189.	.133	130.	13.
12	364.	p	3.95	1	.100	2.6	18.	19.	40.	.70	110.	60.	186.	.065	129.	13.
13	364.	p	6.70	1	.700	2.5	25.	10.	40.	1.70	118.	60.	193.	.171	128.	13.
14	364.	p	3.82	1	.200	2.6	23.	18.	40.	0	120.	60.	200.	.000	138.	13.
15	377.	p	5.70	1	.300	3.1	20.	18.	40.	2.40	95.	60.	183.	.195	113.	15.
16	370.	s	.64		.217	3.1	16.	24.	40.	.65	96.	60.	180.	.053	120.	12.
17	370.	s	1.40	6.8	.430	3.1	19.	21.	47.	0	104.	60.	158.	.000	123.	13.
18	384.	s	2.03		.480	3.1	20.	20.	40.	2.30	101.	60.	185.	.199	121.	13.
19	348.	s	2.03		.510	3.0	16.	23.	40.	1.80	98.	60.	180.	.150	121.	15.
20	377.	s	2.03	7.0	.430	3.5	20.	23.	40.	1.40	112.	60.	179.	.133	135.	13.
21	377.	pc	3.66		.890	2.2	24.	15.	40.	1.20	103.	60.	182.	.105	116.	12.
22	390.	pc	3.95	6.51	.100	2.2	23.	12.	40.	.72	102.	60.	178.	.062	114.	14.
23	377.	pc	3.39	6.7	.850	3.1	20.	26.	44.	1.90	93.	60.	171.	.151	119.	13.
24	371.	pc	4.01	6.21	.200	2.9	20.	20.	43.	0	104.	60.	179.	.000	124.	13.
25	371.	pc	5.22	6.5	.850	3.2	18.	23.	41.	2.20	100.	60.	181.	.188	123.	13.
26	364.	pc	4.56	6.6	.000	6.6	16.	16.	43.	2.40	102.	60.	184.	.209	118.	13.
27	364.	pc	4.90	6.01	.000	3.3	18.	20.	40.	2.40	97.	60.	180.	.199	117.	14.
28	364.	pc	2.93	6.11	.200	2.8	19.	18.	40.	2.40	112.	60.	180.	.232	131.	15.
29	364.	pc	4.88	6.0	.300	4.6	18.	15.	40.	2.40	100.	60.	182.	.205	115.	13.
30	364.	pc	4.41	6.12	.000	2.1	21.	15.	40.	2.40	100.	60.	181.	.188	115.	13.
31	364.	p	5.37	6.11	.600	2.7	4.	12.	20.	2.30	81.	20.	167.	.159	93.	14.
32	364.	p	5.37	6.21	.400	2.9	20.	19.	40.	2.30	84.	40.	180.	.165	103.	14.
33	364.	p	4.27	6.21	.400	3.0	4.	0.	4.	2.40	87.	4.	150.	.179	87.	12.
34	361.	p	4.10	6.31	.300	2.8	18.	30.	40.	2.30	90.	60.	180.	.177	120.	13.
35	377.	p	4.90	6.01	.500	2.5	18.	21.	40.	2.30	83.	40.	189.	.163	104.	15.
36	377.	p	4.90	6.21	.500	2.8	0.	0.	0.	2.40	50.	60.	150.	.103	50.	13.
37	377.	p	4.46	6.3	.000	6.3	18.	19.	40.	2.30	94.	60.	185.	.185	113.	11.
38	364.	p	4.70	1	.200	3.3	0.	0.	0.	1.80	56.	60.	120.	.086	56.	13.
39	377.	p	3.87	1	.200	3.3	0.	0.	0.	.70	48.	60.	120.	.028	48.	13.
40	387.	pc	4.79	1	.000	3.3	0.	0.	0.	2.40	59.	60.	120.	.121	59.	14.
41	380.	pc	4.63	1	.100	3.3	0.	0.	0.	2.00	53.	60.	160.	.090	53.	14.
42	377.	pc	4.79	1	.100	3.3	0.	0.	0.	.70	49.	60.	140.	.029	49.	13.
43	364.	s	1.36		.250	3.8	0.	0.	0.	2.40	55.	60.	180.	.113	55.	13.
50	374.	pc	4.98	5.91	.100	3.3	0.	0.	0.	2.40	34.	30.	60.	.070	34.	15.
51	374.	pc	4.48	5.91	.100	3.3	0.	0.	0.	2.50	64.	60.	120.	.137	64.	14.
52	374.	pc	5.08	1	.100	3.3	0.	0.	0.	2.40	34.	30.	60.	.070	34.	15.
53	374.	pc	4.52	1	.100	3.3	0.	0.	0.	2.30	65.	60.	120.	.128	65.	14.
54	374.	pc	4.45	1	.100	3.3	0.	0.	0.	2.20	34.	29.	60.	.064	34.	15.
55	374.	pc	4.63	1	.100	3.3	0.	0.	0.	2.30	50.	60.	120.	.098	50.	15.
56	364.	pc	4.50	1	.100	3.3	0.	0.	0.	2.60	34.	40.	60.	.076	34.	14.
57	364.	pc	3.89	6.21	.100	3.3	0.	0.	0.	2.50	50.	55.	120.	.107	50.	15.
58	374.	pc	4.63	6.11	.100	3.3	0.	0.	0.	2.50	32.	39.	60.	.068	32.	15.
59	374.	pc	4.60	6.11	.100	3.3	0.	0.	0.	2.50	32.	39.	120.	.068	32.	15.
60	374.	pc	4.81	6.11	.100	3.3	21.	15.	40.	2.20	107.	63.	178.	.201	122.	17.
61	374.	pc	4.44	6.01	.100	3.7	20.	20.	40.	2.20	14.	60.	173.	.026	34.	17.
0	367.	pc		1	.143	3.2	9.	20.	41.	2.50	101.	60.	190.	.216	121.	
01	384.	pc		5.9	.000	5.9	17.	9.	40.	2.20	108.	60.	180.	.203	117.	
06	364.	s	1.82	6.8	.000	6.8	18.	20.	40.	2.30	90.	60.	178.	.177	110.	
07	370.	s	1.73	7.0	.400	3.5	21.	17.	40.	2.30	108.	60.	182.	.212	125.	
08	364.	s	2.14	6.6	.550	3.0	18.	20.	40.	.40	104.	60.	182.	.035	124.	
09	364.	s	1.64	6.9	.400	2.9	17.	23.	40.	.00	100.	60.	180.	.000	123.	

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TABLE A-2. BUCHNER FUNNEL TEST DATA

RUN DATA			BUCHNER FUNNEL DATA								REL SPECIF RESIS			
SAMPLE	%TS	%TVS	b	mls	%TS	gms	gms	w1	w2	w3	r1	r2	r3	
1rs	2.37	1.58	.0640	88.						.0269			17.44	
1cs1	2.36	1.64	.3680	44.						.0536			50.36	
1cs3	2.49	1.71	.5200	34.						.0732			52.12	
1cs5	2.49	1.66	.3970	36.	3.20	1.26				.0692	125.20		63.35	
2rs	2.49	1.67	.0310	90.	24.9			.0350		.0277			8.22	
2cs1	2.49		.0710	78.						.0319			16.32	
2cs3	2.49		.0490	78.						.0319			11.27	
2cs5	2.58	1.67	.0830	76.	10.70	1.78		.0234		.0339	26.01		17.95	
3rs	2.27	1.38	.0400	90.	22.70	1.92	100.40	.0286	.0253	.0252	10.28	11.59	11.64	
3cs1	2.54		.3060	56.	5.10	1.87	97.10	.0334	.0388	.0400	67.26	57.83	56.15	
3cs3	2.35		.2010	68.	6.90	1.91	99.60	.0281	.0344	.0346	52.53	42.86	42.69	
3cs5	2.63	1.75	.1610	70.	9.10	1.67	88.20	.0239	.0331	.0376	49.53	35.66	31.45	
3as	2.36	1.46												
4rs	1.62	.84	.0400	94.	23.1					.0172			17.04	
4cs1	1.77	.84	.0320	92.						.0192			12.21	
4cs3	1.94	1.21	.0310	94.						.0206			11.03	
4cs5	1.91	1.18	.0330	92.	22.1					.0208			11.67	
5rs	3.70	2.33	.1670	72.						.0514			23.85	
5cs1	3.70		1.1260	27.						.1370			60.31	
5cs3	3.70		1.1700	23.						.1609			53.38	
5cs5	3.33	2.21	1.6250	24.	4.30	3.23		.1346		.1388	88.63		85.96	
6rs	.76	.33	.73	95.	15.70	.55		.0058		80	9.26		6.70	
6cs3	.76		1.3250	30.						.0253			383.90	
6cs4	.76		1.2110	31.						.0245			362.57	
6cs5	.60	.02	.9242	24.						.0250			271.35	
7rs	.70													
7cs1	.70		.0141	95.						74			14.05	
7cs4	.70		.0313	90.	16.30	.68		.0076		78	30.41		29.54	
7cs5	.70		.1242	90.	8.30	.73		.0081		78	112.39		117.21	
8rs	1.30		.0242	84.	11.00	1.04		.0124		.0155	14.35		11.48	
8cs1	1.30		.1136	60.						.0217			38.48	
8cs3	1.30		.0445	92.	18.40	.69		.0075		.0141	43.55		23.12	
8cs5	1.30		.0713	92.	16.60	.74		.0080		.0141	65.06		37.04	
9rs	1.36	.94	.0355	84.						.0162			16.09	
9cs1	1.95	1.26	.4700	48.						.0406			84.92	
9cs3	2.00	1.32	.5778	44.						.0455			93.30	
9cs5	2.13	1.41	.5140	44.						.0484			77.93	
10rs	1.67	1.26	.0480	82.						.0204			17.30	
10cs1	1.53	1.15	.0610	80.						.0191			23.41	
10cs3	1.46		.0820	78.						.0187			32.16	
10cs5	1.09	.91	.3000	54.						.0202			109.09	
07rs	1.73	.99	.0700	77.	9.90	1.77		.0230		.0225	22.35		22.87	
07cs1	1.97		.0291	70.	12.20	1.34		.0191		.0281	11.16		7.59	
07cs3	2.00		.0383	66.	14.80	1.16		.0176		.0303	15.99		9.28	
07cs5	2.25	1.32	.0805	60.	11.00	1.01		.0168		.0375	35.10		15.76	
07as	1.97	1.17	.0294	85.	16.40	1.61		.0189		.0232	11.39		9.31	
11rs	4.23	2.43	.0360	88.	32.70	4.15	101.30	.0483	.0498	.0492	5.48	5.30	5.37	
11cs1	3.36		.9270	25.	4.80	2.82	96.70	.1128	.1300	.1344	60.32	52.35	50.63	
11cs3	3.47		.4730	44.	3.60	1.46	87.80	.0332	.0692	.0789	104.63	50.14	44.02	
11cs5	3.22	****	.3330	50.	46.10	2.70	98.70	.0540	.0636	.0644	45.26	38.45	37.95	
12rs	3.53	2.07	.0560	86.	27.40	3.42	100.20	.0398	.0411	.0410	10.34	9.99	10.01	
12cs1	3.43		1.2500	26.	4.90	3.03	95.00	.1165	.1253	.1319	78.73	73.21	69.55	
12cs3	3.84		.9190	30.	5.30	2.64	94.70	.0880	.1212	.1280	76.65	55.65	52.70	
12cs5	3.91	2.56	.4980	42.	6.40	2.66	90.50	.0633	.1209	.0931	57.75	35.52	39.26	
12as	3.66	2.18												

TABLE A-2. BUCHNER FUNNEL TEST DATA
(continued)

RUN DATA			BUCHNER FUNNEL DATA								REL SPECIF RESIS		
SAMPLE	%TS	%TVS	b	mls	%TS	gms	gms	w1	w2	w3	r1	r2	r3
23cs5	3.45	2.19	.8260	36.	6.40	2.34		.0650		.0958	93.27		63.26
24rs	4.01	2.48	.5730	40.	7.55	3.37		.0842		.1003	49.92		41.95
24as	4.21	2.52											
24cs1	3.97		1.3200	20.	5.89	2.59		.1295		.1985	74.82		48.81
24cs3	4.25		1.9600	20.	4.77	1.72		.0860		.2125	167.28		67.70
24cs5	4.22	2.63	1.6800	22.	5.55	2.62		.1191		.1918	103.54		64.29
25rs	5.22	3.53	.2720	58.	6.95	2.40	97.20	.0414	.0875	.0900	48.25	22.82	22.18
25as	4.57												
25cs1	4.61		1.0700	30.	6.47	2.55		.0850		.1537	92.40		51.11
25cs3	4.51		.6220	40.		2.88	95.20	.0720	.1073	.1128	63.4	42.53	40.49
25cs5	4.78	2.60	.7120	39.	8.66	2.22	94.00	.0577	.1167	.1242	90.63	44.78	42.09
26rs	4.36		.3296	50.	9.26	3.86	97.90	.0772	.0854	.0872	31.34	28.34	27.74
26as	4.36												
26cs1	4.21												
26cs3	4.40		1.0150	30.	6.47	3.62	93.10	.1207	.1365	.1467	61.74	54.56	50.80
26cs5	4.33	2.39	1.2030	24.	5.71	3.39	90.90	.1413	.1640	.1804	62.51	53.84	48.94
27rs	4.88	2.87	.5602	45.	8.74	3.60	89.70	.0800	.0973	.1084	51.40	42.27	37.92
27as	4.98	2.95	.1755	67.			92.70		.0689	.0743		18.70	17.33
27cs1	5.51		.9996	34.	9.83	3.44	74.50	.1012	.1207	.1621	72.52	60.77	45.27
27cs3	5.00		.6209	39.	9.08	3.13	77.10	.0803	.0988	.1282	56.79	46.11	35.55
27cs5	5.15	2.43	.6040	40.	9.89	2.54	70.10	.0635	.0903	.1288	69.82	49.12	34.43
28rs	2.93	2.24	.5170	44.	7.68	3.60	97.00	.0818	.0646	.0666	46.38	58.75	56.99
28as	4.04	2.15											
28cs1	4.14		2.0670	20.	5.77	2.48	69.60	.1240	.1441	.2070	122.35	105.31	73.29
28cs3	3.45		1.9000	22.	5.94	2.50	69.80	.1136	.1095	.1568	122.72	127.41	88.93
28cs5	4.12	2.19	1.8300	22.	6.91	2.34	62.10	.1064	.1163	.1873	126.29	115.50	71.73
29rs	4.88	3.02	.5992	42.	8.30	3.83	92.40	.0912	.1074	.1162	48.23	40.97	37.85
29as	4.47	2.68	.2274	66.			94.60		.0641	.0677		26.05	24.64
29cs1	4.89		.7457	35.	7.25	3.24	84.20	.0926	.1176	.1397	59.13	46.53	39.18
29cs3	5.03		1.0250	30.	7.32	3.25	80.10	.1083	.1343	.1677	69.45	56.02	44.87
29cs5	4.84	2.76	.6963	38.	6.90	3.36	83.10	.0884	.1084	.1274	57.80	47.15	40.13
30rs	4.41	2.64	.4651	46.	8.09	3.60	96.60	.0783	.0926	.0959	43.62	36.86	35.61
30as	4.74	2.69	.8028	30.			101.30		.1601	.1580		36.82	37.29
30cs1	5.16												
30cs3	5.03		2.7200	18.	6.94	3.40	65.40	.1889	.1828	.2794	105.70	109.24	71.44
30cs5	5.16	3.17	1.5520	24.	6.48	3.49	84.10	.1454	.1808	.2150	78.34	63.00	52.98
31rs	5.37	3.24	.4178	46.	10.21	4.69	94.80	.1020	.1107	.1167	30.08	27.71	26.27
31as	5.45	3.21	.5599	32.			99.40		.1693	.1703		24.28	24.13
31cs1	5.31		.7461	32.	8.20	4.64	92.60	.1450	.1537	.1659	37.77	35.64	33.00
31cs3	5.59		.7220	34.	7.93	4.14	91.80	.1218	.1509	.1644	43.52	35.11	32.23
31cs5	5.55	3.39	.7943	32.	7.71	4.28	91.10	.1338	.1580	.1734	43.59	36.90	33.62
32rs	5.17	3.09	.4178	44.	9.32	4.43	99.20	.1007	.1166	.1175	30.46	26.31	26.10
32as	5.84	3.32	.9973	20.			96.70		.2824	.2920		25.92	25.07
32cs1	5.63		.5998	36.	8.74	4.29	88.60	.1192	.1386	.1564	36.94	31.77	28.15
32cs3	6.09		.7093	34.	8.62	4.00	84.40	.1176	.1512	.1791	44.25	34.44	29.07
32cs5	6.64	3.98	.6617	36.	8.95	4.02	87.60	.1117	.1616	.1844	43.49	30.06	26.33
33rs	4.27	2.39	.3492	52.	9.90	3.84	95.60	.0738	.0783	.0821	34.71	32.65	31.21
33as	4.74	2.69	.2854	54.			97.60		.0857	.0878		24.45	23.87
33cs1	4.62		.5810	36.	6.62	3.85	99.30	.1069	.1274	.1283	39.88	33.46	33.23
33cs3	4.48		.6042	34.	6.59	3.90	98.90	.1147	.1303	.1318	38.66	34.03	33.66
33cs5	4.59	2.49	.4165	40.	7.11	3.64	96.50	.0910	.1107	.1148	33.59	27.61	26.64
34rs	4.10	2.49	.3416	54.	9.54	3.67	99.60	.0680	.0756	.0759	36.89	33.16	33.02
34as	4.24	2.58	.9816	28.			98.00		.1484	.1514		48.55	47.58
34cs1	4.91		1.6900	24.	5.28	3.33		.1388		.2046	89.40		60.63
34cs3	4.12		1.1160	26.	6.19	3.08	81.80	.1185	.1296	.1585	69.15	63.20	51.69

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TABLE A-2. BUCHNER FUNNEL TEST DATA
(continued)

RUN DATA			BUCHNER FUNNEL DATA								REL SPECIF RESIS		
SAMPLE	%TS	%TVS	b	mls	%TS	gms	gms	w1	w2	w3	r1	r2	r3
13rs	6.70	3.72	.1700	66.	19.20	5.02	100.00	.0761	.1015	.1015	16.40	12.30	12.30
13cs1	6.07		1.9800	24.	8.10	5.32	91.50	.2217	.2314	.2529	65.56	62.80	57.46
13cs3	6.44		1.0700	30.	9.90	4.67	81.50	.1557	.1750	.2147	50.45	44.89	36.59
13cs5	6.11	3.48	1.0100	34.	9.70	4.08	78.40	.1200	.1408	.1797	61.80	52.60	41.30
13as	6.42	3.47											
14rs	3.82	2.36	.1290	70.	21.30	4.10	100.50	.0586	.0548	.0546	16.17	17.26	17.35
14cs1			1.6300	25.	5.00	3.42	97.60	.1368			87.46		
14cs3	3.91		1.2500	26.	6.00	3.82	97.20	.1469	.1462	.1504	62.45	62.77	61.01
14cs5	3.92	2.61	1.2200	26.	5.40	3.47	95.50	.1335	.1440	.1508	67.10	62.19	59.39
14as	4.40	2.70											
15rs	5.70		.0920	76.	25.90	4.47	98.30	.0588	.0737	.0750	11.48	9.16	9.00
15as	4.94												
15cs1	5.13		1.1160	30.	8.90	5.28	98.10	.1760	.1678	.1710	46.54	48.83	47.90
15cs3	5.29		.3710	44.	9.90	4.49	97.30	.1020	.1170	.1202	26.69	23.28	22.65
15cs5	6.39		.2930	52.	12.80	4.27	100.50	.0821	.1235	.1229	26.19	17.41	17.50
16rs	.64	.41	.0100	90.						71			10.32
16as	.64		70	80.						80			6.42
16cs1	.86	.62	.0860	84.						.0102			61.66
16cs3	.77	.51	.0220	80.						96			16.78
16cs5	.79	.44	.0450	90.		.47				88	63.25		37.63
17rs	1.40	.67	.0380	70.	12.20	1.31	99.00	.0187	.0198	.0200	14.90	14.09	13.95
17as			.0900	80.	9.70	1.16	98.00	.0145			45.56		
17cs1	1.37		.2290	40.	5.90	1.16	94.60	.0290	.0324	.0343	57.96	51.88	49.08
17cs3	1.43		.5150	50.	2.50	.75	96.40	.0150	.0276	.0286	252.01	137.11	132.17
17cs5	1.09	.61	.7230	35.	3.10	.66	93.40	.0189	.0291	.0311	281.42	182.44	170.40
18rs	2.03	1.39	.0940	70.						.0290			23.79
18as			.0500	74.									
18cs1	1.69	1.13	.3090	54.						.0313			72.47
18cs3	1.73	1.00	.0650	54.						.0320			14.89
18cs5	1.41	.98	.1330	56.	21.20	1.00		.0179		.0252	54.67		38.77
19rs	2.03	1.03	.0770	70.	5.97	.98	100.40	.0140	.0291	.0290	40.37	19.41	19.49
19as			.2770	50.	3.54	1.57	96.40	.0314			64.75		
19cs1	1.43		.0660	74.	15.70	1.31	92.40	.0177	.0179	.0193	27.37	27.13	25.07
19cs3	1.15		.1050	74.	18.80	1.30	88.90	.0176	.0138	.0155	43.87	55.79	49.59
19cs5	1.25	.59	.1700	60.	21.60	1.03	80.20	.0172	.0167	.0208	72.69	74.68	59.89
20rs	2.03	1.17	.0780	60.						.0338			16.92
20as			.0370	70.									
20cs1	1.89		.0850	60.						.0315			19.81
20cs3	2.03		.1030	70.						.0290			26.07
20cs5	1.93	1.11	.1470	70.	15.70	1.32		.0189		.0276	57.22		39.13
21rs	3.66	2.19	.3140	57.	9.12	3.14		.0551		.0642	41.84		35.89
21as													
21cs1	3.79		.5530	36.	4.80	2.00	97.70	.0556	.1029	.1053	73.06	39.46	38.56
21cs3	3.80		.5380	30.	5.50	2.57	94.20	.0857	.1193	.1267	46.10	33.10	31.18
21cs5	3.76	2.14	.6430	32.	4.98	2.12	92.70	.0662	.1089	.1175	71.24	43.33	40.17
22rs	3.95	2.41	.3600	52.	8.74	3.57	96.90	.0687	.0736	.0760	38.49	35.90	34.79
22as	4.59	2.24											
22cs1	4.76		1.3270	24.	5.24	2.99	85.60	.1246	.1698	.1983	78.18	57.37	49.11
22cs3	4.63		.9820	28.	3.13	1.27	74.50	.0454	.1232	.1654	158.91	58.51	43.59
22cs5	4.48	2.73	1.0940	28.	7.29	3.22	76.50	.1150	.1224	.1600	69.83	65.60	50.19
23rs	3.39	2.05	.2270	54.	11.57	3.02		.0559		.0628	29.79		26.54
23as	3.46	1.91											
23cs1	3.56		.2190	54.	12.57	2.34		.0433		.0659	37.10		24.38
23cs3	3.51		.6460	38.	5.52	2.47		.0650		.0924	72.95		51.33

TABLE A-2. BUCHNER FUNNEL TEST DATA
(continued)

RUN DATA				BUCHNER FUNNEL DATA								REL SPECIF RESIS			
SAMPLE	%TS	%TVS	b	mls	%TS	gms	gms	w1	w2	w3	r1	r2	r3		
34cs5	3.89	2.40	.5683	36.	7.41	2.83	83.70	.0786	.0904	.1081	53.06	46.12	38.60		
35rs	4.88	2.88	.6096	38.	7.97	4.18	94.40	.1100	.1212	.1284	40.68	36.91	34.84		
35as	4.13	2.74	.7592	32.			97.00		.1252	.1291		44.51	43.18		
35cs1	5.92		1.1540	26.	7.74	3.51	76.70	.1350	.1746	.2277	62.74	48.50	37.20		
35cs3	5.16		.2339	32.	7.58	3.42	79.40	.1069	.1280	.1612	16.06	13.41	10.65		
35cs5	5.25	3.10	.9072	30.	7.39	3.34	79.30	.1113	.1388	.1750	59.81	47.98	38.05		
36rs	5.02	3.10	.3688	50.	9.90	4.25	95.70	.0850	.0961	.1004	31.85	28.17	26.96		
36as	4.92	2.97	.4783	42.			98.50		.1154	.1171		30.43	29.97		
36cs1	4.74		.4407	43.	7.43	3.80	98.60	.0888	.1092	.1107	36.43	29.62	29.21		
36cs3	5.75		.8430	34.	8.27	3.39	79.00	.0997	.1336	.1691	62.06	46.31	36.59		
36cs5	5.33	3.29	1.0510	28.	5.44	3.13	96.60	.1102	.1813	.1877	70.00	42.55	41.10		
06rs	1.82	.99	.0268	90.	14.31	1.58	101.30	.0176	.0205	.0202	11.21	9.60	9.73		
06as	1.76	.99	.0389	90.			101.00		.0198	.0196		14.46	14.60		
06cs1	1.81		.0987	80.	7.69	1.39	100.70	.0174	.0228	.0226	41.70	31.80	32.02		
06cs3	1.74		.2679	60.	4.21	1.36	94.20	.0227	.0273	.0290	86.75	71.98	67.81		
06cs5	1.93	1.08	1.2510	32.	2.89	1.07	69.20	.0334	.0417	.0603	274.61	220.01	152.25		
07rs	1.73		.0700	77.	9.86	1.77	97.50	.0230	.0219	.0225	22.35	23.45	22.87		
07as	1.97		.0294	85.	16.40	1.61	95.20	.0189	.0221	.0232	11.39	9.78	9.31		
07cs1	1.97		.0291	70.	12.19	1.34	85.80	.0191	.0241	.0281	11.16	8.85	7.59		
07cs3	2.00		.0383	66.	14.83	1.16	77.80	.0176	.0236	.0303	15.99	11.92	9.28		
07cs5	2.25		.0805	60.	10.98	1.01	73.40	.0168	.0275	.0375	35.10	21.50	15.76		
09rs	1.64	.92	.0136	90.	13.50	1.22	100.40	.0136	.0183	.0182	7.36	5.46	5.48		
09as	1.88	1.06	.0112	95.			.00		.0198	.0198		4.15	4.15		
09cs1	1.84		.0291	80.	13.38	.99	98.10	.0124	.0226	.0230	17.26	9.47	9.29		
09cs3	1.99		.0793	80.	13.01	1.09	90.80	.0136	.0226	.0249	42.72	25.77	23.40		
09cs5	1.62	.88	.0347	80.	7.09	1.07	98.80	.0134	.0200	.0203	19.04	12.73	12.58		
08rs	2.14	1.25	.0420	80.	9.74	1.90	99.90	.0237	.0267	.0268	12.98	11.54	11.52		
08as	2.42	1.37	.0150	80.			95.70		.0289	.0303		3.80	3.64		
08cs1	2.55		.0350	80.	17.10	1.71	85.50	.0214	.0273	.0319	12.02	9.43	8.06		
08cs3	2.44		.0550	80.	17.20	1.58	88.60	.0198	.0270	.0305	20.44	14.94	13.24		
08cs5	2.60	1.58	.0480	80.	14.40	1.73	91.70	.0216	.0298	.0325	16.29	11.82	10.84		
37rs	4.46	2.63	.3110	56.	9.48	3.60	97.40	.0643	.0776	.0796	35.51	29.43	28.66		
37as	3.66	2.14	.3540	46.			99.50		.0792	.0796		32.82	32.66		
37cs1	3.66		.8940	30.	6.08	3.52	94.00	.1173	.1147	.1220	55.93	57.22	53.79		
37cs3	3.66		1.3600	23.	5.26	2.03	89.40	.0902	.1454	.1627	110.64	68.64	61.37		
37cs5	4.40	2.61	1.1100	26.	5.91	3.35	89.60	.1288	.1516	.1692	63.23	53.73	48.14		
38rs	4.70	2.62	.3970	48.	8.87	4.09	95.20	.0852	.0932	.0979	34.20	31.26	29.76		
38as	4.46	2.32	.1870	60.	12.20	3.59	95.20	.0598	.0708	.0743	22.94	19.40	18.47		
38cs60	4.34		.3810	50.	8.57	3.34	92.10	.0668	.7994	.0868	41.86	35.50	32.22		
38cs120	4.65		.4950	44.	8.99	3.21	85.50	.0730	.0904	.1057	49.80	40.21	34.38		
39rs	3.87	2.13	.3060	53.	8.50	3.69	98.60	.0696	.0720	.0730	32.26	31.20	30.76		
39as	4.55	2.58	.1450	64.	13.30	3.74	96.70	.0584	.0687	.0711	18.21	15.48	14.97		
39cs60	4.76		.4340	45.	8.63	3.63	92.00	.0807	.9732	.1058	39.49	33.20	30.12		
39cs120	4.70	2.59	.6540	38.	8.44	3.33	83.00	.0876	.1027	.1237	54.78	46.76	38.81		
40rs	4.79	2.59	.6090	40.	3.98	3.98	92.60	.0995	.1109	.1198	44.93	40.31	37.33		
40cs60	4.96		.5240	43.	8.41	3.59	88.20	.0835	.1017	.1153	46.07	37.80	33.34		
40cs120	3.90	2.23	.9110	34.	8.78	3.19	74.80	.0938	.0858	.1147	71.27	77.93	58.29		
41rs	4.63	2.59	.6210	40.	8.48	3.85	92.50	.0962	.1071	.1158	47.36	42.57	39.38		
41as	4.56	2.48	.1860	65.	13.20	3.72	94.00	.0572	.0659	.0702	23.85	20.70	19.46		
41cs60	4.72		.4060	48.	8.83	3.62	91.10	.0754	.0896	.0983	39.51	33.27	30.31		
41cs170	5.03	2.81	.6570	39.	8.28	3.26	82.20	.0836	.1060	.1290	57.69	45.49	37.39		
42rs	4.79	2.72	.5880	41.	8.32	4.29	95.20	.1046	.1112	.1168	41.25	38.80	36.94		
42rs			.0380	66.	17.10	3.89	87.70	.0589			4.73				
42as	5.04	2.75	.1630	67.	15.30	3.92	94.30	.0585	.0709	.0752	20.45	16.87	15.90		
42cs60	4.81		.5130	42.	9.40	3.60	82.10	.0857	.0940	.1145	43.93	40.05	32.88		

TABLE A-2. BUCHNER FUNNEL TEST DATA
(continued)

RUN DATA				BUCHNER FUNNEL DATA							REL SPECIF RESIS		
SAMPLE	%TS	%TVS	b	mls	%TS	gms	gms	w1	w2	w3	r1	r2	r3
42cs120	4.92	2.64	.7940	35.	8.12	2.90	75.80	.0829	.1066	.1406	70.34	54.70	41.46
43rs	1.36	.64	.0170	85.	8.83	1.17	100.50	.0138	.0161	.0160	9.07	7.76	7.80
43rs			.0160	85.	8.95	1.23	99.90	.0145			8.12		
43as	1.54		.36	90.	14.00	1.29	101.40	.0143	.0174	.0171	1.84	1.52	1.54
43cs60	1.50		.0160	85.	12.30	1.14	95.50	.0134	.0169	.0176	8.76	6.97	6.65
43cs120	1.66	.46	.0240	85.	11.10	1.13		.0133		.0195	13.25		9.02
50rs	4.98	2.79	.4589	42.	8.28	4.08	93.00	.0971	.1103	.1186	34.67	30.55	28.41
50as	5.22		.3186	52.	9.79	4.49	100.80	.0863	.1012	.1004	27.08	23.11	23.30
50cs60	4.95		.3986	45.	9.29	3.89	90.70	.0864	.0998	.1100	33.85	29.32	26.60
51rs	4.48	2.51	.5784	41.	7.61	4.04	96.00	.0985	1.0490	.1093	43.09	40.50	38.85
51as	4.74		.1784	65.	12.43	3.84	97.00	.0591	.0707	.0729	22.17	18.51	17.96
51cs120	5.47		.8440	39.	9.14	3.44	78.10	.0882	.1095	.1403	70.23	56.55	44.17
52rs	5.08	2.86	.5562	40.	9.01	4.37	89.60	.1092	.1138	.1270	37.37	35.88	32.15
52as	4.48		.1816	60.	11.84	3.87	99.70	.0645	.0744	.0747	20.67	17.91	17.85
52cs60	4.67		.4743	43.	8.18	3.59	89.30	.0835	.0970	.1086	41.70	35.90	32.06
53rs	4.52	2.59	.4433	45.	10.43	4.29	99.80	.0953	.1002	.1004	34.13	32.46	32.39
53as	4.75		.1356	60.	16.03	4.11	100.00	.0685	.0792	.0792	14.53	12.57	12.57
53cs120	4.78		.4738	44.	9.09	3.49	84.60	.0793	.0919	.1086	43.84	37.84	32.01
54rs	4.45	2.49	.6405	40.	7.63	4.09	96.50	.1023	.1074	.1113	45.98	43.79	42.26
54as	4.59		.2715	52.	9.71	4.09	97.90	.0787	.0864	.0883	25.34	23.06	22.58
54cs60	4.56		.4412	43.	8.68	3.84	89.10	.0893	.0945	.1060	36.26	34.27	30.54
55rs	4.63	2.49	.6346	40.	8.15	4.04	92.00	.1010	.1065	.1158	46.12	43.74	40.24
55as	4.75		.0819	60.	18.18	3.84	95.50	.0640	.0756	.0792	9.39	7.95	7.59
55cs120	5.47		.7651	35.	11.15	2.99	69.40	.0854	.1085	.1563	65.3		35.90
56rs	4.50	2.33	.4444	45.	8.08	4.22	98.70	.0938	.0987	.1000	34.78	33.05	32.62
56as	4.71		.1443	70.	15.38	4.08	100.10	.0583	.0674	.0673	18.17	15.74	15.74
56cs60	4.54		.3305	50.	10.60	3.40	86.80	.0680	.0788	.0908	35.67	30.78	26.72
57rs	3.89	2.00	.3038	55.	8.76	3.71	9.50	.0675	.0067	.0707	33.06	31.87	31.53
57as	4.73		.1233	66.	14.47	4.16	98.70	.0630	.0707	.0717	14.36	12.79	12.63
57cs60													
57cs120	5.54		.4381	45.	10.84	3.49	79.00	.0776	.0973	.1231	41.46	33.06	26.12
58rs	4.63	2.36	.4605	43.	8.36	4.39	99.80	.1021	.1075	.1077	33.11	31.45	31.39
58as	4.20		.1526	64.	14.18	4.04	97.80	.0631	.0642	.0656	17.74	17.45	17.07
58cs60	4.80		.1973	63.	12.55	4.14	97.90	.0657	.0746	.0762	22.04	19.42	19.01
58float		5.20	1.2380	26.	10.57								
59rs	4.59	2.30	.5177	45.	8.63	4.18	96.40	.0929	.0983	.1020	40.91	38.65	37.25
59as	4.55		.1372	66.	14.45	3.81	100.00	.0577	.0689	.0689	17.44	14.61	14.61
59cs120	4.47		.7856	36.	9.67	2.93	67.80	.0814	.0842	.1242	70.95	68.50	46.44
60rs	4.81	2.24	.5648	41.	8.44	4.39	94.60	.1071	.1110	.1173	38.72	37.35	35.34
60as	5.05	2.43											
60cs30	4.91		.5786	40.	9.65	3.14	74.30	.0785	.0912	.1227	54.10	46.57	34.60
60cs60	5.36												
60cs90	5.36	2.54	.3608	52.	11.46	3.54	85.80	.0681	.0884	.1031	38.90	29.94	25.69
60cs150	4.70		.2615	60.	12.97	3.59	89.40	.0598	.0700	.0783	32.08	27.41	24.50
61rs	4.44	2.05	.4908	43.	7.88	4.09	96.60	.0951	.0997	.1033	37.87	36.12	34.89
61as	4.78												
61cs30	4.79		.3279	48.	8.90	3.59	90.60	.0748	.0904	.0998	32.18	26.62	24.12
61cs90	4.51	2.05	.4243	43.	9.85	2.83	72.80	.0658	.0764	.1049	47.32	40.79	29.69
61cs150	4.74		.5456	40.	9.02	2.89	73.60	.0723	.0872	.1185	55.43	45.92	33.79
cond			.0253	70.	14.50	3.84	98.50	.0549			3.41		
cond			.0268	70.	15.15	3.77	95.40	.0539			3.65		

TABLE A-3. BUCHNER FUNNEL TEST RESULTS WITH POLYMER CONDITIONING

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POLYMER DATA SUMMARY

SAMPLE	%TS	b	FILTR ml/s	CAKE %TS	pH	DOSE gm/kg	CAKE gm	BF gm	w1	w2	w3	r1	r2	r3
8rs	1.30	.0247	70.	11.00	7.10	0.0	1.27		.0181		.0186	9.79		9.56
8rs	1.30	.0182	70.	11.30	7.10	2.30	1.30		.0186		.0186	7.19		7.19
8cs1	1.30	.0047	70.	13.20	7.10	8.00	1.33		.0190		.0186	1.82		1.86
8cs1	1.30	.1136	60.		3.20	0.0					.0217			38.48
8cs1	1.30	.0146	82.	18.20	3.20	11.50	.85		.0104		.0159	10.34		6.76
8cs3	1.30	.0133	94.	20.20	3.20	34.60	.68		.0072		.0138	13.49		7.06
8cs3	1.30	.0445	86.	18.40	3.20	0.0	.69		.0080		.0151	40.71		21.61
8cs3	1.30	.0181	90.	17.80	3.20	11.50	.66		.0073		.0144	18.12		9.20
8cs5	1.30	.0150	80.	18.20	3.20	34.60	1.02		.0127		.0162	8.64		6.78
8cs5	1.30	.0713	92.	16.60	3.20	0.0	.74		.0080		.0141	67.44		38.39
8cs5	1.30	.0118	80.	19.20	3.20	11.50	.68		.0085		.0162	10.19		5.33
6rs	.70	.0211	80.	16.20	3.20	5.80	.92		.0115		.0162	13.47		9.53
6rs	.70	.0073	80.	15.70	6.70	0.0					.0088			6.12
6rs	.70	.0021	90.	14.50	6.70	2.10					.0078			1.98
6rs	.70	.0005	90.	15.80	6.70	10.70					.0078			.47
19rs	2.03	.0055	50.	13.90	6.80	16.00	1.91	100.3	.0382	.0407	.0406	1.06	.99	.99
19cs5	1.25	.0340	60.	16.40	3.50	21.00	1.41	96.7	.0235	.0201	.0208	10.6	12.39	11.98
17rs	1.40	.0027	70.	15.30	6.60	21.40	1.34	99.3	.0191	.0199	.0200	1.04	1.00	.99
17cs5	.66	.0220	70.	15.80	3.40	21.40	1.10	94.1	.0157	.0089	.0094	10.28	18.20	17.13
21rs	3.66	.0040	74.		6.00	16.40		100.0		.0495	.0495		.59	.59
21cs1	3.79	.0630	60.		3.50	39.50		97.0		.0613	.0632		7.55	7.32
21cs2	3.80	.0700	60.		3.60	19.70		95.0		.0602	.0633		8.54	8.11
21cs5	3.76	.0730	60.		3.70	23.90		94.4		.0592	.0627		9.06	8.55
01rs	4.10	.0030	50.	6.50	5.90	25.60	.77		.0154		.0820	1.43		.27
01cs1	4.10	.0034	60.	6.70	6.00	43.90	.68		.0113		.0683	2.20		.37
01cs3	4.10	.0400	49.	4.30	6.00	25.60	.70		.0143		.0837	20.55		3.51
01cs3	5.10	.0140	27.		6.00	20.60					.1889			.54
01cs5	5.10	.0590	60.		6.00	35.30					.0850			5.09
01cs5	6.10	1.0300	24.	5.20	6.00	17.20					.2542			29.75
0rs	6.10	.0020	50.	6.40	6.00	29.50	.68		.0136		.1220	1.08		.12
0rs	4.03	.0850	40.			18.75	1.43		.0357		.1007	17.45		6.19
0cs5	4.03	.0010	50.			37.50	1.43		.0286		.0806	.26		.09
0cs5	3.34	.0270	55.		3.50	44.90	1.30		.0236		.0607	8.38		3.26
0cs5	3.34	.0180	55.		3.50	63.40	1.30		.0236		.0607	5.59		2.18
26rs	3.34	1.0200	24.		3.50	44.90	1.30		.0542		.1392	138.22		33.80
26rs	4.36	.0179	56.	15.52	6.30	18.60	4.05	98.0	.0723	.0763	.0779	1.82	1.72	1.69
cs5	4.33	.5416	36.	7.25	6.20	18.70	3.33	92.9	.0925	.1117	.1203	42.98	35.58	33.05
30rs	4.41	.0341	60.	19.18	6.10	18.40	3.93		.0655		.0735	3.82		3.41
cs5	5.17	.2403	40.	16.45	2.20	15.70	2.38	67.2	.0595	.0869	.1293	29.64	20.31	13.65
cs5	5.17	.1957	60.	14.60	2.20	31.30	2.80	83.8	.0467	.0722	.0862	30.78	19.89	16.67
27rs	4.88	.4580	50.	9.39	6.00	4.10	3.82	92.2	.0764	.0900	.0976	44.00	37.36	34.44
27rs	4.88	.0990	50.	14.55	6.00	12.50	3.90	92.9	.0780	.0907	.0976	9.32	8.01	7.45
27rs	4.88	.0640	55.	17.51	6.00	16.60	3.78	90.5	.0687	.0803	.0887	6.84	5.85	5.29
27rs	4.88	.0177	55.	14.60	6.00	24.90	3.94	96.5	.0716	.0856	.0887	1.81	1.52	1.46
27rs	4.88	.0042	70.	13.70	6.00	33.20	4.01	100.7	.0573	.0702	.0697	.54	.44	.44
27rs	4.88	.0021	60.	12.98	6.00	49.70	4.08	103.3	.0680	.0840	.0813	.23	.18	.19
27cs5	5.24	.2545	55.	16.57	3.70	3.90	2.59	72.0	.0471	.0686	.0953	39.67	27.23	19.61
27cs5	5.24	.1388	50.	24.52	3.70	11.60	2.57	72.5	.0514	.0760	.1048	19.82	13.41	9.72
27cs3	5.24	.0441	45.	14.43	3.70	15.50	3.03	81.9	.0673	.0954	.1164	4.81	3.39	2.78
27cs5	5.24	.0379	50.	19.30	3.70	23.20	3.19	90.3	.0638	.0946	.1048	4.36	2.94	2.65

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TABLE A-3. BUCHNER FUNNEL TEST RESULTS WITH POLYMER CONDITIONING

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POLYMER DATA SUMMARY

SAMPLE	%TS	b	FILTR ml	CAKE %TS	pH	DOSE gm/kg	CAKE gm	BF gm	w1	w2	w3	r1	r2	r3
27cs5	5.24	.0639	65.	17.99	3.70	30.90	3.29	93.4	.0506	.0753	.0806	9.27	6.23	5.82
27cs5	5.24	.0539	50.	14.27	3.70	46.40	3.19	91.0	.0638	.0954	.1048	6.20	4.15	3.78
37rs	4.40	.2250	52.	10.40	6.30	4.60	3.29	95.6	.0633	.0809	.0846	26.10	20.42	19.52
37rs	4.40	.0550	60.	19.70	6.30	13.60	3.88	88.8	.0647	.0651	.0733	6.24	6.20	5.50
37rs	4.40	.0290	54.	20.00	6.30	18.40	3.89	97.3	.0720	.0793	.0815	2.95	2.68	2.61
37rs	4.40	.0064	60.	17.40	6.30	27.20	3.96	97.3	.0660	.0714	.0733	.71	.66	.64
37rs	4.40	.0025	70.	17.10	6.30	36.30	4.09	105.7	.0584	.0664	.0629	.31	.28	.29
37cs5	4.40	.0051	80.	16.80	6.30	54.50	3.92	108.9	.0490	.0599	.0550	.31	.26	.28
37cs5	4.40	.0133	62.	15.80	6.30	55.20	3.66	92.5	.0590	.0656	.0710	1.65	1.49	1.38
37cs5	4.40	.1020	70.	15.70	6.30	36.80	3.61	82.9	.0516	.0521	.0629	14.52	14.37	11.91
37cs5	4.40	.3560	49.	7.60	6.30	27.60	3.62	95.6	.0739	.0858	.0898	35.37	30.44	29.10
37cs5	4.40	.4780	40.	7.00	6.30	18.40	3.52	95.6	.0880	.1052	.1100	39.87	33.36	31.90
37cs5	4.40	.5210	40.	7.20	6.30	13.80	3.61	104.7	.0903	.1152	.1100	42.37	33.20	34.76
37cs5	4.40	.7700	32.	6.60	6.30	4.60	3.75	108.7	.1172	.1495	.1375	48.23	37.81	41.10
38rs	4.70	.0180	55.	17.80	6.00	20.60	3.93	95.8	.0715	.0819	.0855	1.85	1.61	1.55
38cs120	4.65	.0980	70.	22.70	3.70	21.20	3.35	91.2	.0479	.0606	.0664	15.03	11.87	10.83
38cs120	4.65	.1680	60.	15.70	6.50	0.0	3.19	87.7	.0532	.0680	.0775	23.19	18.14	15.91
38cs120	4.65	.0050	60.	18.00	6.50	50.80	3.29	95.8	.0548	.0742	.0775	.67	.49	.47
39rs	3.87	.3070	53.	9.73	6.10	23.20	3.49	91.9	.0658	.0671	.0730	34.22	33.58	30.86
39cs120	4.70	.1070	60.	19.30	3.70	27.70	2.92	80.6	.0487	.0631	.0783	16.14	12.44	10.03
39cs120	4.70	.2050	65.	17.50	6.50	0.0	3.09	87.8	.0475	.0635	.0723	31.65	23.70	20.81
39cs120	4.70		60.	22.80	6.50	24.50	3.31	92.2	.0552	.0722	.0783			.00
40rs	4.79	.0760	45.	14.80	5.40	21.20	3.82	91.4	.0849	.0973	.1064	6.57	5.73	5.24
40cs120	3.90	.2420	48.	15.70	3.90	28.10	2.88	79.5	.0600	.0646	.0813	29.60	27.50	21.86
40cs120	3.90	.3920	50.	9.63	6.50	0.0	3.09		.0618		.0780	46.56		36.89
40cs120	3.90	.0300	50.	21.30	6.50	28.30	2.86		.0572		.0780	3.85		2.82
41rs	4.63	.0540	50.	17.60	5.90	20.80	3.00		.0600		.0926	6.61		4.28
41cs120	5.03	.1460	55.	18.50	3.70	27.20	2.97	82.0	.0540	.0750	.0915	19.85	14.29	11.72
41cs120	5.03	.2300	55.	14.00	6.50	0.0	3.12	85.7	.0567	.0784	.0915	29.76	21.54	18.46
41cs120	5.03	.0350	55.	20.50	6.50	25.90	3.13	90.2	.0569	.0825	.0915	4.51	3.11	2.81
42rs	4.79	.0380	55.	17.10	5.80	20.80	3.89	87.7	.0707	.0764	.0871	3.94	3.65	3.20
42cs120	4.92	.1490	55.	20.00	5.90	28.00	2.89	84.1	.0525	.0752	.0895	20.81	14.54	12.23
42cs120	4.92	.0750	55.	20.90	6.50	25.60	3.16	75.8	.0575	.0678	.0895	9.58	8.12	6.15
42cs120	4.92	.2710	55.	16.10	6.50	0.0	3.08	80.1	.0560	.0717	.0895	35.52	27.76	22.24
42cs120	4.92	.7940	35.	8.10	3.80	0.0	3.60	75.8	.1029	.1066	.1406	56.66	54.70	41.46
43rs	1.36	.0010	90.	13.50	6.50	63.20	1.28	104.3	.0142	.0158	.0151	.52	.47	.49
43cs120	1.66	.0024	90.	15.00	4.40	66.30	2.44	100.3	.0271	.0370	.0184	.65	.96	.96
43cs120	1.66	.2660	65.	.38	6.40	0.0	1.24	101.2	.0191	.0258	.0255	102.35	75.54	76.49
43cs120	1.66	.0510	75.	13.80	6.50	69.20	1.17	90.2	.0156	.0200	.0221	24.00	18.75	16.91
43cs120	1.66	.1030	8.	15.10	6.50	36.10	2.49		.0286		.0191	26.42		39.62
50rs	4.98	.0879	50.	13.53		20.60	3.94	96.2	.0788	.0958	.0996	8.19	6.73	6.48
50cs60	4.95	.1878	65.	16.72	6.70	0.0	3.71		.0571		.0762	24.15		18.10
50cs60	4.95	.0572	65.	22.90	6.70	19.40	3.71	94.4	.0571	.0719	.0762	7.36	5.84	5.51
50cs60	4.95	.0102	75.	18.34	6.70	32.10	3.74	99.5	.0499	.0657	.0660	1.50	1.14	1.13
51rs	4.48	.0874	55.	15.68		20.60	3.94	93.7	.0716	.0763	.0815	8.96	8.41	7.88
51cs120	5.47	.1554	60.	18.96	6.70	0.0	3.89		.0648		.0912	17.59		12.51
51cs120	5.47	.0754	70.	22.75	6.70	24.00	3.38	96.4	.0483	.0753	.0781	11.46	7.35	7.08
51cs120	5.47	.0627	80.	19.66	6.70	34.90	3.44	100.1	.0430	.0684	.0684	10.70	6.72	6.73
52rs	5.08	.0120	60.	15.02		19.30	4.19	86.7	.0698	.0734	.0847	1.26	1.20	1.04
52cs60	4.67	.1769	70.	18.29	6.70	0.0.	3.88		.0554		.0667	23.43		19.46

A-4. QUALITY ASSURANCE DATA

Buchner Funnel Tests

Data for the individual replicate runs is included in Table A-4, and was summarized and discussed in Section 4 of this report.

Solids Analyses

Table A-5 presents results of replicate analyses on varying samples for total solids and volatile solids. The results were quite consistent, with less than five percent variation between means on all samples except for two results, one of which was an obvious error, probably in data recording.

TABLE A-4-a. BUCHNER FUNNEL RESULTS OF REPLICATE TESTS

Sample	TS	b	mls	w	r	i
0 CS-5*	3.34	1.53	23	.1452	77.3	4.5
		1.48	26	.1285	84.6	
01 RS*	4.09	1.000	37	.1105	66.40	7.4
		0.8627	40	.1023	61.90	1.0
		0.8464	38	.1076	57.7	0.5
		0.8555	35	.1169	53.74	2.1
		0.8200	40	.1023	58.9	
4 RS*	1.62	0.040	94	.0174	17.07	5.1
		0.037	92	.0176	15.42	
25 RS	5.22	0.251	58	.0414	44.5	4.0
		0.272	58	.0414	48.2	
07 CS1	1.97	0.0291	70	.0191	11.2	7.1
		0.0314	75	.0179	12.9	0.4
		0.0285	82	.0163	12.8	6.7
07 CS3	2.00	0.0383	66	.0176	16.0	5.6
		0.0376	75	.0154	17.9	4.8
		0.0338	82	.0141	17.6	0.8
Plant Conditioned	4.23	0.0108	70	.063	1.26	0.4
		0.0107	64	.063	1.25	
35 AS	4.13	0.6096	38	.110	40.6	6.0
		0.7673	34	.123	45.8	
43 RS	1.36	.017	85	.0137	9.1	5.8
		.016	85	.0145	8.1	
Plant Conditioned		.0255	70	.0549	3.4	2.9
		.0268	70	.0539	3.6	

*-r based on % TS

TABLE A-4-b. TS/TVS QUALITY ASSURANCE/QUALITY CONTROL DATA
REPLICATE ANALYSES

Run Number	Percent TS	i	Percent TVS	i
OCS 5 Cake	5.73	7.3	62.0	4.4
	6.63		57.7	
OCS 5	3.34	2.0	61.9	0.2
	3.21		62.2	
14 RS	3.82	1.5	61.7	0.4
	3.71		62.2	
37 RS	4.46	0.5	59.0	0.2
	4.42	0.2	58.8	0.5
	4.40	0.7	58.2	0.7
37 CS 5	4.40	1.8	59.2	2.1
	4.56	1.0	56.8	0.7
	4.47	0.8	56.0	2.8
35 RS	4.93	0.5	58.3	1.0
	4.88		59.5	
36 RS	5.02	1.8	61.8	0.2
	4.84		61.5	
30 CS 5	5.16	0.3	61.5	
	5.19		36.8	**
30 RS	4.41	0.0	59.8	3.3
	4.41		56.0	
27 RS	4.88	0.2	58.8	1.3
	4.90	0.7	60.3	2.0
	4.95	0.7	62.8	3.3
27 CS 5	5.24	0.7	61.7	1.5
	5.31	1.5	59.9	1.2
	5.15	0.9	58.5	2.7
29 AS	4.47	0.2	59.9	2.8
	4.45		63.3	
06 CS 1	1.81	2.5	-	
	1.72		-	
09 CS 3	1.99	2.6	-	
	1.89		-	
59 RS	4.59	0.1	50.1	3.0
	4.60		47.2	
	$\bar{x}$ 1.2		$\bar{x}$ 1.7	
	si 1.5		si 1.3	
	3 si 4.5		3 si 3.9	
	1 value > 3 si		1 value > 3 si	

A-4-c. Duplicate Pilot Plant Runs

Several runs during the course of the study were repeated. Results from runs during which conditions were essentially the same, testing similar sludges are shown in Table A-6. As can be observed, results were similar in general; however, there were occassionally significantly large differences, particularly for runs 9 and 17 on secondary sludge. Fairly consistent results were observed on duplicates during the final series of runs 50 to 59 data. These results simply illustrate differences in specific resistance and cake solids measured on sludges from similar test conditions, and provide a guide for interpretation of the study results.

DUPLICATE PILOT PLANT RUNS SLUDGE COMBINED SLUDGE

Run Conditions: pH 3 to 4, 100% O_3, 4.14×10^5 Pa, Contact time ∿ 180 minutes
TS = 5.2 4.9

Run Number:	25		27	
	r	Cake	r	Cake
rs	48.3	6.95	51.4	8.74
CS 1	92.4	6.47	72.5	9.83
CS 3	63.4	-	56.8	9.08
CS 5	90.6	8.66	69.8	9.89

Run Conditions: pH 3 to 4, 100% O_3, 2.07×10^5 Pa, Contacted time ∿ 60 minutes
TS = 5.0 5.1 4.5

Run Number:	50		52		54	
	r	Cake	r	Cake	r	Cake
rs	34.7	8.3	37.4	8.2	46.0	7.6
AS	33.9	9.8	20.7	10.4	25.3	9.7
CS 60	43.1	9.3	41.7	16.0	36.3	8.7

Run Conditions: pH 3 to 4, 100% O_3, $4 \times 14 \times 10^5$ Pa, Contact time 120 minutes

Run Number:	51		53		55	
	r	Cake	r	Cake	r	Cake
rs	43.1	7.6	34.1	10.4	46.1	8.2
AS	22.2	12.4	14.5	16.0	9.4	18.2
CS 120	70.2	9.1	43.8	9.1	65.3	11.1

Run Conditions: pH 3 to 4, 100% O_3, 2.76×10^5 Pa, Contact time 60 minutes

Run Number	56		58	
	r	Cake	r	Cake
rs	34.8	8.1	33.1	8.4
AS	18.2	15.6	17.7	14.2
CS 60	35.7	10.6	22.0	12.6

Run Conditions: pH 3 to 4, 0% O_3, 4.14×10^5 Pa, Contact time ∿ 180 minutes
TS Run 17 = 1.40 Run 09 = 1.64

Run Number	17		09	
	r	Cake	r	Cake
rs	14.9	12.2	7.4	13.5
AS	45.6	9.7	-	-
CS 1	58.0	5.9	17.3	13.4
CS 3	252.0	2.5	42.7	13.0
CS 5	281.0	3.1	19.0	7.1

Run Conditions: pH 3 to 4, 100% O_3, 4.14×10^5 Pa, Contact time ∿ 180 minutes
1 to 2% TS

Run Number	08		07	
	r	Cake	r	Cake
rs	13.0	11.0	22.4	9.9
AS	-	-	11.4	16.4
CS 1	12.0	-	11.2	21.2
CS 3	20.4	18.4	16.0	14.8
CS 5	16.3	16.6	35.1	10.9

r = specific resistance cm/g x 10^{11}
Cake = percent total solids in filter cake

TABLE A-5-a. COD ANALYSES

Run Number	Type of Sludge	Raw Sludge		Acidified Sludge	Contacted Sludge	
		Total	Filtered	Filtered	Total	Filtered
0	C	47,000	1,400	3,900	40,000	2,800
1	C	51,000	1,200	-	48,000	5.700
6	S	20,000	100	84	18,000	2,200
7	S	16,000	560	850	16,000	590
8	S	16,000	550	820	11,000	1,300
9	S	13,000	600	640	10,000	1,500
10	S	13,000	110	850	19,000	2,400
1	P	27,000	1,600	-	29,000	2,100
2	P	38,000	1,000	1,400	26,000	1,300
3	P	27,000	770	2,500	24,000	2,400
4	P	16,000	1,200	470	25,000	1,300
5	P	35,000	480	2,000	43,000	3,400
11	P	36,000	1,300	1,100	28,000	2,100
12	P	20,000	840	1,500	34,000	2,300
13	P	26,000	1,700	3,800	33,000	5,100
14	P	12,000	1,400	2,400	43,000	2,700
15	P	17,000	2,100	2,200	49,000	3,300
16	S	5,900	160	140	5,500	800
09	S	15,000	54	-	17,000	460
17	S	16,000	90	910	11,000	900
18	S	18,000	650	920	18,000	1,700
19	S	15,000	390	840	17,000	1,500
20	S	14,000	350	760	15,000	910
21	C	31,000	1,400	2,200	32,000	2,600
22	C	36,000	2,200	2,600	37,000	3,500
23	C	29,000	510	1,700	3,400	2,300
24	C	40,000	2,500	3,200	30,000	3,500
25	C	28,000	840	2,400	54,000	2,800
26	C	36,000	2,100	2,200	39,000	4,000
27	C	41,000	2,900	2,900	39,000	4,000
28	C	28,000	2,100	2,800	31,000	3,500
29	C	42,000	2,700	2,500	41,000	3,800
30	C	43,000	2,100	2,900	32,000	4,500
31	P	45,000	3,100	6,600	57,000	4,000
32	P	47,000	2,700	3,200	43,000	5,000
33	P	40,000	1,600	2,900	25,000	3,300
34	P	39,000	2,800	2,300	37,000	3,600
35	P	46,000	4,300	4,600	39,000	3,800
36	P	49,000	2,000	2,700	49,000	3,400
37	P	42,000	1,300	1,200	37,000	3,600
38	P	51,000	6,100	2,600	34,000	3,200
39	P	46,000	1,900	2,200	44,000	2,600
40	C	45,000	6,100	3,900	43,000	3,600
41	C	58,000	6,100	3,200	43,000	3,500
42	C	51,000	4,100	3,000	51,000	2,900
43	S	14,000	63	560	18,000	840
50	C	52,000	3,200	3,000	63,000	4,900
51	C	40,000	3,600	3,000	41,000	3,400
52	C	-	-	-	-	-
53	C	-	-	-	-	-
54	C	-	-	-	-	-
55	C	-	-	-	-	-
56	C	39,000	2,500	1,900	41,000	2,600
57	C	36,000	1,900	1,900	46,000	1,500
58	C	45,000	1,900	1,200	48,000	2,600
59	C	41,000	1,800	2,600	42,000	1,900
60	C	-	-	-	-	-
61	C	-	-	-	-	-

Types of Sludge:

P - Primary
S - Secondary
C - Combined

ABLE A-5-b. ANALYSES OF TOTAL AND FILTERED SAMPLES FOR BOD, NUTRIENTS AND HEAVY METALS

Run/Sludge		pH	% TS	% TVS	Results in mg/kg Wet Weight															
					BOD_5		TKN		NH_3-N	PO_4-P		Fe		Zn		Cr		Pb		Cu
					T	F	T	F		T	F	T	F	T	F	T	F	T	F	
3-P	RS	6.0	2.27	1.38	1600	920	760	40	170	270	0.87	280	4.8	23	0.4	0.9	<0.2			
	AS	2.3	2.36	1.46									120		4.7		0.4			
	CS-5	3.2	2.43	1.75	4000	1300	760	62	480	190	37		23		16		0.5			
8-S	RS		1.3	-	1900	590	170	27	25	200	2.3	150	1.3	14	0.02	0.43	<0.04			
	AS	3.3	1.3	-									34		8.1		0.12			
	CS-5	3.3	1.3	-	2250	650	210	82	5.6	160	17		3.9		11		0.17			
13-P	RS		6.70	3.72	4800	4000	1400	76	410	610	3.9	650	7.5	50	0.4	1.7	<0.2			
	AS	2.5	6.42	3.48									450		5.1		<0.2			
	CS-5	3.44	6.11	3.47	10000	1500	1600	110	170	540	44		140		28		0.7			
19-S	RS	6.0	2.03	1.03	2000	500	660	44	150	340	2.3	3.9	1.5	27	<0.01	0.7	<0.2			
	AS	3.0	-	-					230		23		100		14		<0.2			
	CS-5	3.5	1.25	0.59	2800	530	1100	98	84	350	32		14		23		<0.2			
23-C	RS	6.6	3.39	2.05	1800	350	1400	11	240	370	15									
	AS	3.0	3.46	1.91					120		26									
	CS-5	3.5	3.45	2.19	900	730	1400	100	290	380	23									
31-P	RS	6.1	5.37	3.24	2700	2400	1700	110	560	620	8.9									
	AS	2.7	5.45	3.21			1600	210	120	580	180									
	CS-5	2.9	5.55	3.39	3200	1600	1500	200	170	590	97									
50-C	RS		4.98	2.79	2300	1700	2000	170	120	690	7.8	680	19	65	<0.1	2.2	<0.2	6.3	<0.5	17 <0.1
	AS	3.5	5.22	-					66		14		120		<0.4		<0.2			
	CS-60	3.8	4.95	-	4500	3500	2100	200	76	660	12	650	150	54	25	2.3	<0.2	6.0	<0.5	17 <1.0
51-C	RS	5.9	4.48	2.51	4500	3500	1700	160	120	690	6.3	760	17	69	<0.2	2.3	<0.2	7.3	<0.5	20 <0.1
	AS	3.5	4.74	-					82		19		130		<0.2		<0.2		<0.5	<0.1
	CS-120	3.8	5.47	-	6700	1600	2100	180	77	640	15	670	65	53	33	2.1	<0.2	6.3	<0.5	19 1.0
56-C	RS		4.50	2.33	10400	4200	1500	150	100	660	5.5	830	22	68	0.2	2.5	<0.2	6.2	<0.5	18 <0.1
	AS	3.3	4.71	-					53		20		140		0.4		<0.2		<0.5	<0.1
	CS-60	3.7	4.54	-	7600	1400	1400	140	45	630	15	88-0	91	52	31	2.6	<0.2	6.0	<0.5	17 0.4
57-C	RS	6.2	3.89	2.00	6600	4700	1500	150	99	580	9.1	800	15	62	<0.1	2.5	<0.2	5.5	<0.5	16 <0.1
	AS	3.3	4.73	-									150		0.3		<0.2		<0.5	<0.1
	CS-120	3.7	5.54	-	6500	1400	1400	120	37	610	16	620	38	52	29	2.1	<0.2	4.6	<0.5	14 <0.8
58-C	RS	6.1	4.63	2.36	8200	1700	1400	130	79	630	5.2	560	6.4	86	<0.1	3.6	<0.2	8.6	<0.5	22 <0.1
	AS	3.5	4.20	-					52		12		170		0.4		<0.2		<0.5	<0.1
	CS-	3.8	4.80	-	5500	1500	1600	140	48	660	10	210	190	9.5	6.9	0.4	<0.2	<0.5	<0.5	1.9 <0.1
59-C	RS	6.1	4.59	2.30	6900	3200	1700	170	120	680	5.5	820	22	64	<0.1	2.6	<0.2	6.2	<0.5	18 <0.1
	AS	3.3	4.55	-					75		14		180		0.4		<0.2		<0.5	<0.1
	CS-	3.7	4.47	-	5800	3300	1600	150	79	600	13	700	75	49	37	2.6	<0.2	6.5	<0.5	18 <0.1

TABLE A-5-c. CANTON ANALYTICAL LABORATORY
QUALITY ASSURANCE/QUALITY CONTROL RESULTS

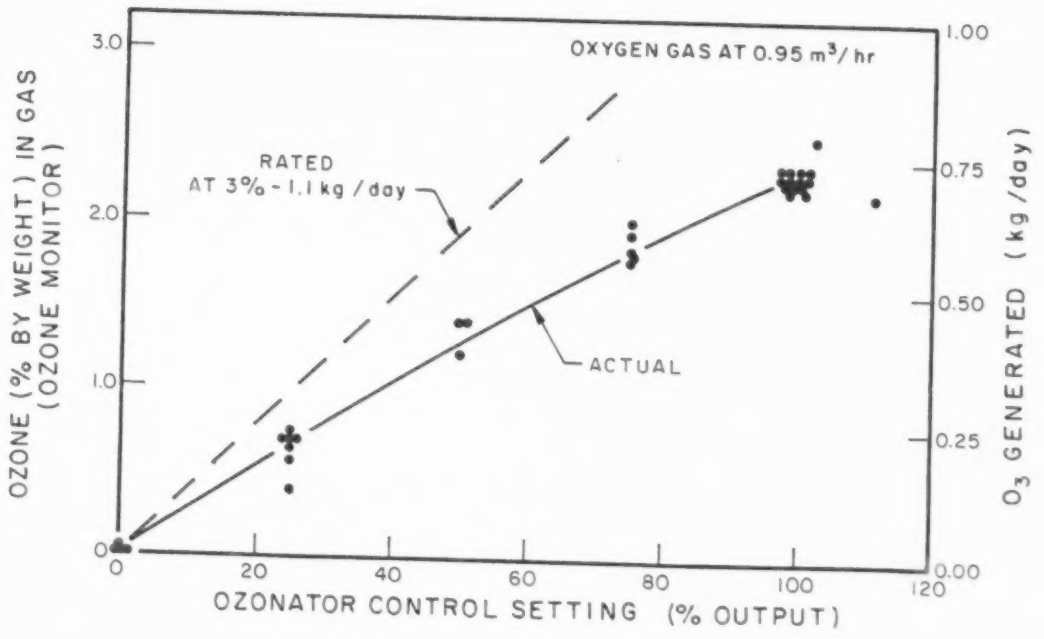
	Standard Recovery		Dup ($\frac{\lvert A-B \rvert}{A+B}$)		Spike Recovery		
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	n
P	97.4	4.1	4.0	3.2	90.6	11.5	14
NH_3	101.0	4.7	2.1	2.6	109.0	6.3	7
COD	99.7	5.4	2.9	2.5	103.0	20.4	32
TKN	100.0	0.0	4.1	2.7	94.7	26.2	9
Cr	101.0	3.6	8.6	*	101.0	8.4	6
Cu	97.0	0.0	3.0	*	97.0	2.5	3
Fe	96.7	5.2	2.8	*	105.0	14.8	5
Pb	96.5	2.0	2.3	*	96.2	2.3	3
Zn	97.1	1.9	12.6	*	98.3	6.9	4

* Several duplicate results were less than the method detection limit.

TABLE A-6. OZONATOR/MONITOR CALIBRATION OUTPUT

Ozonator Output Control Setting Percent	Ozone Monitor Percent O_3	KI Test Percent O_3	Percent Deviation from KI
0 (ozonator off)	-	-	-
25	0.775	0.7702	0.6
50	1.336	1.3390	0.2
50	1.343	1.339	0.3
75	2.076	2.1186	2.0
100	2.597	2.7913	6.9
100	2.414	2.2635	6.7
125	3.039	3.0389	0
25	0.632	0.6238	1.3
0 (ozonator off)	0.000	0.0	0.0

Note: 25 percent output minimum setting on ozonator.
Gas Oxygen - 0.79 m^3/hr (28 SCFH) at 103 kPa (15 psi).



A-7. BUCHNER FUNNEL TEST PROCEDURES

The Buchner funnel test is used to determine sludge filterability and optimum chemical dosages.

I. Equipment

1. Buchner funnel w/graduated filtrate receiver
2. Whatman No. 2 filter paper
3. Sludge conditioning chemical: polymers, lime, etc.
4. Vacuum flask and tubing
5. Stop watch
6. Miscellaneous items such as beakers, syringes, stands, spatula

II. Procedure

Buchner Funnel Test

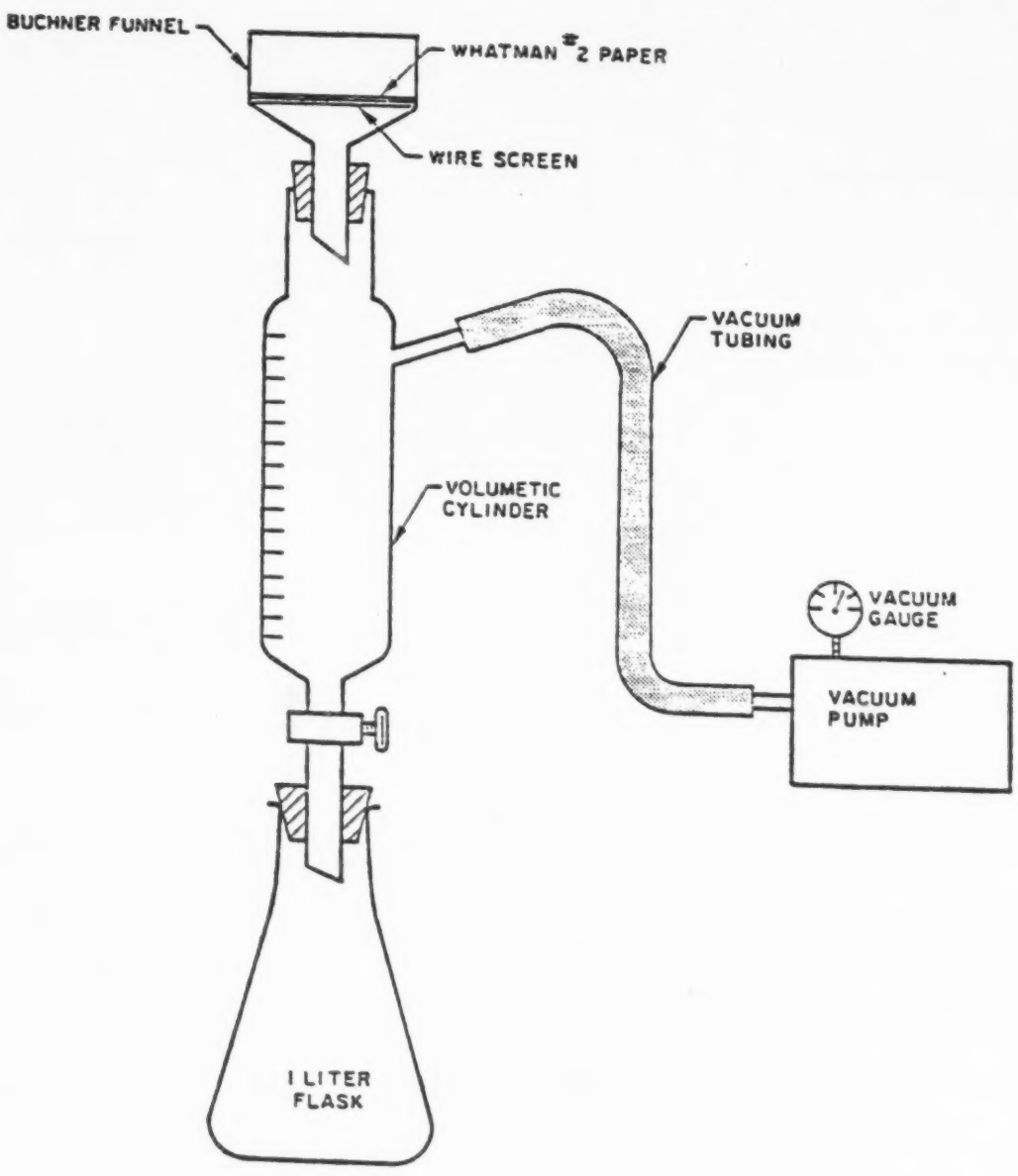
1. Set up Buchner funnel apparatus as shown in the figure.
2. Determine approximate chemical dosages by conditioning several samples of sludge with increasing chemical dosages until a good floc, and water-sludge separation is observed. If non-conditioned sludges, only, are to be tested, steps two, three, six and eight are not required.
3. Condition 200 ml samples of sludge with known chemical dosages in 5 to 8 incremental steps from 0 to 125% of estimated optimum dosage.
4. Wet the filter paper, then pour a conditioned sample into the funnel and apply a vacuum of about 103 kPa (15 in. of Hg).
5. Record filtrate volume (V) and time (t) every 10 or 15 seconds until the vacuum breaks or cake cracks. Time interval may be adjusted based on rate of filtrate volume. Vacuum may not break for unconditioned sample, therefore, run test only as long as required to obtain several volume and time data points, required to develop a plot.
6. Repeat 4 and 5 with each conditioned sample.
7. Calculate t/V values and plot t/V versus V for each run. Calculate relative specific resistance (b) which is the slope of the line of best fit through the straight line portion of the plot.
8. Plot "b" versus chemical dosage. The lowest point of the curve is the theoretical optimum chemical dosage. Normally a dosage beyond the minimum point should have been tested.
9. Samples of sludge cakes and filtrate at one or two optimum dosages may be collected for analyses on selected tests.
10. Specific resistence "r" may be calculated to compare dewaterability of different sludges and solids concentrations using the following formula:

$$r = \frac{2PA^2b}{\mu w}$$

P - pressure (dynes/cm^2)
A - filter area (cm^2)
μ - filtrate viscosity (poise)
w - mass of dry solids per unit volume of filtrate g/cm^3
b - relative specific resistence (slope of T/V vs. V) sec/ml^2

For purposes of this study the pressure will normally be 103 kPa (15 psi), the funnel area constant and filtrate viscosity essentially constant (water at 20°C), with w and b being the variables.

Reference: Water Supply and Pollution Control, 3rd Edition by John W. Clark, Warren Viesman, Jr., and Mark Hammer; IEP, Dun-Donnelly, New York (1977).



BUCHNER FUNNEL APPARATUS

TABLE A-8. PILOT PLANT DATA SHEET

HYDROQUAL, INC.

HYPERBARIC OXYOZOSYNTHESIS PILOT PLANT DATA SHEET

SLUDGE SAMPLE No. _____ RUN No. _____ DATE _____ PERSONNEL _____
HQI / GO / IWWRT

SLUDGE TYPE: _____ (%P, %S, C) VOLUME $_{0}$ _____ L(1) ACID ADDED _____ ml. pH INITIAL ____ FINAL ____

TIME t	Δ t	REACTOR PRESS.	O_2 VOLUME	Δ O_2 USED	O_3 GENERATOR			O_3 CONC. %	Δ O_3 USED	EXIT GAS FLOW	GAS O_3	TEMP. °C	SAMPLE No.	NOTE #
					% OUTPUT	PRESS.	GAS FLOW scfm							

NOTES AND COMMENTS:

(1) VOLUME AND EQUIVALENT ACID (66° Bé H_2SO_4) ADDED TO REACTOR

OZONICS
CORPORATION

Rec'd 5/21/85
HB

May 15, 1985

Dr. Harry Bostian, Ph.D., P.E.
Wastewater Research Division
Municipal Environmental Research
Laboratory
Cincinnati, Ohio 45268

REFERENCE: PLANT PILOT DEMONSTRATION OF HYPERBARIC OXOYOZOSYNTHESIS PROCESS

Dear Dr. Bostian:

Thank you for affording us the opportunity to respond to the draft report on the Oxyozosynthesis pilot study in Monroe, Michigan prepared by Greenhorne and O'Mara, Inc.

Our objections to the study stem from its focus on the oxyozosynthesis process as a pretreatment or conditioning treatment ahead of dewatering and the resulting negative tone of the report based on the conclusion that oxyozosynthesis treatment resulted in no improvement in dewaterability over raw sludges. In our view, oxyozosynthesis is primarily a sludge disinfection and stabilization process. This is the strength and the purpose of our process.

Ozyozosynthesis and many other stabilization processes do impact dewaterability and this impact does need to be evaluated inorder to properly measure the technical and economic viability of any sludge treatment program. The data we have collected indicates that oxyozosynthsis compares favorably with other stabilization processes in terms of its effect on sludge dewaterability. Indeed, the Monroe study's finding that oxoyozsynthesis can produce stable, disinfected sludges with dewaterability equal or close to that of raw untreated sludges is to us a positive result.

We will list below our comments by topic for your review.

26 W. Diamond Avenue, Box 6004, Gaithersburg, Maryland 20877 • (301) 948-8950

POSITIVE PERFORMANCE

The focus on dewaterability and the perceived failure of oxyozosynthesis treatment to improve dewaterability tends to cloud the positive aspects of the system's performance at Monroe.

1. Effective stabilization as evidenced by obvious odor reduction and effective disinfection as measured by reductions in fecal coliforms was achieved over a wide range of operating conditions.

2. Acidification during treatment solubilizes some portion of the heavy metal constituents in the sludges and oxyozosynthesis may be developed as a process for heavy metals removal from contaminated sludges.

3. With oxyozosynthesis, odor control and disinfection can be achieved in sludges without diminishing sludge dewaterability.

DEWATERABILITY STUDY METHODOLOGY

We question the conclusions of the dewaterability study based on the choice of the Buechner Funnel Test as an indicator of specific resistance and dewaterability of polymer conditioned sludges and because of the study's failure to evaluate the performance of a range of conditioning agents.

1. The Buechner Funnel Test is an old method established for vacuum filtration testing of sludges conditioned with inorganic chemicals. In vacuum filter dewatering, a grainy structured floc is required for air passage and drying. Polymer conditioned materials have typically blinded the Buechner Funnel paper rendering test results invalid. Most polymer and belt press manufacturers have demonstrated more reliable indicators of proper conditioning. It should be noted that vacuum filter performance is now determined by a filter leaf test and not by a Buechner Funnel Test.

2. Comments and conclusions regarding dewatering and specific resistance have to be questioned since processed material was not degassed prior to testing. Large quantities of entrained gas will tend to blind-off Buechner Funnel paper and inhibit dewaterability.

3. Oxyozosynthesis processed sludges should be more charged than raw sludges. This charge is probably negative. If one uses the same conditioner as the one used for raw sludge, the quantity required should be greater and the effectiveness should be less. Yet no provision was made to work with different conditioners and conditioning chemicals used were not identified.

In general, one uses a polyelectrolyte such as alum, ferric chloride, etc. with an organic polymer described as anionic, cationic or non-ionic. The conditioners used for raw sludge would be quite different than those required for oxyozosynthesis processed sludge. Properly conditioned oxyozosynthesis processed sludge ought to dewater better than raw sludge since it would have a more homogenious charged characteristic in its sludge matrix.

4. We are enclosing for your review dewatering analysis performed by Komline-Sanderson on Oxyozosynthesis processed sludges from the Linden, N.J. wastewater treatment plant.* These results indicate a potential for excellent dewatering performance from Oxyozosynthesis processed sludges.

SYSTEM COST ANALYSIS

The system cost analysis presented in the report presents inflated and unrealistic costs for construction and operation of an Oxyozosynthesis system. Proposed system process stream and sizing can be improved based on our experience as contractors designing and building Oxyozosynthesis sludge processing facilities. And more importantly, it is a mistake to apply consumable demands derived from the pilot unit to plant scale system operations. Finally, since oxyozosynthesis is a liquid batch process, it is more meaningful to develop operating costs on a per gallon basis.

1. The actual costs of operating a plant scale Oxyozosynthesis facility as reported by Stanley Petersen, Superintendent of wastewater treatment fascilities in West New York, N.J. were in total $110,000 per 1000 Ton Dry Solids per year (report enclosed).* Specifically, oxygen and electricity costs were $8500/1000 TDS in West New York while projected costs for oxygen and electricity stated in the Monroe study are $36,000/1000 TDS. This represents an overstatement of operating costs by a factor greater than 4.

   Ozonics Corporation has constructed an Oxyozosynthesis facility at the wastewater treatment plant in Hoboken, N.J. due for start up in May of 1985. Analysis of consumable usage based on rated demands of installed equipment yields an expected annual operating costs in the range of 80% less than those reported in the Monroe study.

2. Because of the focus on dewaterability, no effort was made to optimize operating costs based on disinfection and stabilization. It was noted that continuous oxyozonation was not required for stabilization and disinfection which alone can cut oxygen consumption on the pilot unit by more than 50%.

* not included with Monroe County project report - Ozonics Corporation may provide this information on direct request.

3. The proposed design in the Monroe study calls for the installation of sludge blending tanks and mixers. In most situations, sludge blending and acidification can be achieved in the reactor vessels ahead of pressurization.

4. Annual O & M costs in the Monroe study include $100,880 for caustic to neutralize processed material ahead of dewatering. Neutralization is not necessary for dewatering in all cases depending on the choice of conditioning agents and on ultimate disposal or reuse options. This item should not be included in the analysis of Oxyozosynthesis costs since no other conditioning, dewatering or disposal costs are addressed.

We are enclosing for your review dewatering analysis from the Linden-Roselle pilot operation, the Petersen report on the operation of the Oxyozosynthesis system in West New York and a letter from Dr. Robert Reimers of Tulane University with his comments on the Monroe study.

Thank you again for your willingness to cooperate with us.

Sincerely,

OZONICS™ CORPORATION

Thomas C. Coyte
Vice President

TCC:jm
Enclosures

9/9/86 Update

The oxyozosynthesis technology is now marketed by Synox Corporation and Ozonics Corporation. Appropriate contacts are:

Mr. Robert D. Blythe
Vice President
Synox Corporation
12 Meem Avenue
Gaithersburg, MD 20877
(301) 948-8088

Mr. James Ginesi
President
Ozonics Corporation
363A Brickyard Road
Freehold, NJ 07728
(201) 780-8886

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* not included with Monroe County project report - Ozonics Corporation may provide this information on direct request.

** This letter is included - see next two pages.

Tulane University Medical Center

School of Public Health and Tropical Medicine
Department of Environmental Health Sciences
1430 Tulane Avenue
New Orleans, Louisiana 70112
(504) 588-5374

May 10, 1985

Mr. Rober Blythe, Agronomist
Ozonics Corporation
26 W. Diamond Avenue
Box 6004
Gaithersburg, Maryland 20877

Dear Bob:

After reviewing the draft EPA report on the Oxyozosynthesis process entitled, "Pilot Plant Demonstration of the Hyperbaric Oxyozosynthesis Process" by Greenhorne and O'Mara, Inc. and HydroQual, Inc., (Feb. 1985), I feel that the report does not necessarily release damaging data, but in fact, yields some very supportive data with observations. In this review the pertinent observations will be elucidated first followed by some observations concerning possible misinterpretations.

The process data noted that the sludge was stabilized by the Oxyozosynthesis process and the pathogens were inactivated. Interestingly, it should be noted in the conclusions that the bacterial inactivation required both the pH drop and the addition of ozone. In addition, the noted metals leaching was no surprise since the sludge pH had been dropped to below 4. At this pH the metal complexes should be positively charged similar to the sludge. Also, there was no noted release of ammonia and phosphorous which is expected, and the COD apparently should not drop with O_3 of 100 mg/l to COD levels at 20 to 30,000 mg/l or more.

There is question concerning the dewatering statement. The oxyo-treated sludge should be more charged than the raw sludge. This charge is probably negative. Obviously, if one uses the same conditoner as the one used for the raw sludge, the quantity should be more and the effectiveness should be less. One question is what were the conditioners? The only comment was an organic polymer. In general, one uses a polyelectrolyte such as alum, ferric chloride, etc. with an organic polymer prescribed as anionic, cationic, or non-ionic. Obviously, the condioners used for raw sludge would be quite different than oxyo-treated sludge, and properly conditioned oxyo-treated sludge ought to dewater better than raw sludge since it would have a more homogenious charged

characteristic in its sludge matrix. For example, the report states that iron appears to be bound in the oxyo-treated sludge. Probably, the reduced ferrous iron is oxidized to ferric iron which forms ferric hydroxide cation. This ion would assist in the condition of the oxyo-treated sludge by neutralizing the negatively charged groups formed by ozone.

Hopefully, these comments will be helpful to you. Sorry for the delay. If you have any further questions, feel free in communicating with me at your convenience.

Sincerely yours,

Bob

Robert S. Reimers, Ph.D.
Associate Professor

RSR:jk

cc: Dick Gray